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GEOLOGY OF

LAS TRAMPAS RIDGE

BERKELEY HILLS, CALIFORNIA

By CORNELIUS K. HAM

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By Cornelius K. Ham *

OUTLINE OF REPORT

Page
Abstract 3
Introduction 3
Stratigraphy 5
  Cretaceous system 5
  Tertiary system 7
    Upper Eocene 7
    San Ramon formation 8
    Monterey formation 8
    San Pablo group 11
    Orinda-Mulholland formations 14
    Pinole tuff 17
  Quaternary system 17
  Igneous rocks 18
Geologic structure 18
  Folds 19
  Faults 19
Geologic history 21
Economic geology 22
Bibliography 23
Appendix 25
  Fossil localities 25
Sorting curves, San Pablo group sediments 26
  Heavy and light mineral analyses 26

Illustrations

Plate 1. Geologic map of the Las Trampas Ridge area, California ..... In pocket
2. Geologic sections through the Las Trampas Ridge area, California ..... In pocket
Figure 1. Index maps showing location of Las Trampas Ridge area 4
2. Radial drainage pattern and tilted terraces of Las Trampas Ridge area 5
3. Geologic column of Las Trampas Ridge area 6
4. Photo showing well-cemented Cretaceous conglomerate, Upper San Leandro Reservoir 7
5. Measured sections of the Monterey formation west and southwest of Mount Diablo 9
6. Photo showing undulating opaline chert of Claremont member 9
7. Photomicrographs of typical graywackes of the San Pablo group 10
8. Photo showing massive Cierbo graywacke near crest of Rocky Ridge 12
9. Photo showing Cierbo graywacke in typical mode of outcrop, Rocky Ridge 12
10. Photo showing massive Cierbo graywacke outcropping as hogback, Rocky Ridge 13
11. Photo showing northwest side of Rocky Ridge 13
12. Stratigraphic position of diagnostic megafossils of the San Pablo group 14
13. Photo showing middle Briones shell breccia bed 14
14. Photo showing swayback structure developed in upper Neroly sands 15
15. Photo showing sand and shale of Mulholland formation 16
16. Photo showing ripple-marked Mulholland beds 16
17. Photomicrographs of coarse porphyritic basalt interbedded in Pinole tuff, and of Pinole tuff 17
18. Photomicrographs of fresh analcite-bearing olivine diabase 18
19. Map showing locations of rock-sample and fossil localities 24
20. Cumulative curves showing sorting in San Pablo group sediments 26

ABSTRACT

Las Trampas Ridge area embraces 33 square miles of eastern Alameda and Contra Costa Counties, California, lying approximately midway between the city of Oakland and Mount Diablo. San Ramon Valley and State Highway 21 adjoin it on the east and State Highway 24 and Walnut Creek lie 2 miles north of the north boundary. The base map used is the U. S. Geological Survey Las Trampas Ridge quadrangle, scale 1:24 000.

The topography is a series of parallel ridges and canyons carved in folded Tertiary and Cretaceous marine sediments and Tertiary continental sediments. Thin pyroclastic and volcanic flow rocks are interbedded with some of the continental sediments. The area is complexly folded and faulted.

The oldest rocks in the area are marine sandstone, shale, and conglomerate of probable Upper Cretaceous age. These are found only in the extreme southwest corner of the quadrangle. They contain no fossils and are assigned to the Cretaceous because of lithologic similarity and stratigraphic position of the known series in adjacent areas.

In the northeast corner of the district, yellowish-brown, fine-grained, marine sandstone beds of probable upper Eocene age are found in a narrow belt adjacent to the Franklin fault. Fossils present in the sandstone are not indicative of the precise stratigraphic position in the Eocene, but the rocks are lithologically similar to upper Eocene strata in the general vicinity.

Lying with probable angular unconformity on the Eocene beds are blue-gray tuffaceous sandstone and siliceous gray shale of Oligocene or Oligo-Miocene age belonging to the San Ramon formation. The beds contain scattered fossils.

Unconformably above the San Ramon formation is the Monterey group of rocks, here divided into four members: the Rodeo shale, undifferentiated middle Monterey beds, Claremont chert, and Sobrante sandstone. Sandstone in the Monterey group contains a middle Miocene fauna similar to Temblor stage faunas of the west side of the San Joaquin Valley.

Conformably above the Monterey group is the San Pablo group subdivided in the Las Trampas Ridge area into five parts: the Neroly sandstone, Cierbo sandstone, and three-member Briones formation, consisting of an upper sandstone, middle shell or reef bed, and lower massive sandstone. San Pablo group rocks contain abundant megafossils indicating an upper Miocene age.

The continental Contra Costa group is made up of three formations, the Orinda, Pinole tuff, and Mulholland. However, the contact between Orinda and Mulholland formations is not distinguishable in Las Trampas Ridge area and the two units have been mapped together. The Orinda formation is predominantly conglomerate, silt, and sand of flood-plain origin, whereas the Mulholland, though lithologically similar in part, is commonly lacustrine in origin. The Orinda beds interfinger with rocks of the upper Miocene San Pablo group and are in part contemporaneous. Lower Pliocene vertebrate remains have been found in the Orinda and middle Pliocene vertebrates and plant fossils in the Mulholland. Between the Mulholland formation and members of the San Pablo group in the northern part of the area, is the middle Pliocene Pinole tuff. It is believed to be younger than the Orinda beds and older than the Mulholland units on the basis of vertebrate and plant fossils as well as stratigraphic evidence.

Valley fill and terrace remnants of Quaternary age complete the lithologic units in the area of Las Trampas Ridge. Some of the terrace deposits have yielded Pleistocene vertebrate fossils.

INTRODUCTION

Location. Las Trampas Ridge area is about 8 miles due east of Oakland, astride the boundary of northern Alameda County and southern Contra Costa County, California. Being readily accessible from major centers of population, the area is best reached by the paved all-weather state highways 21 or 24. Highway 21, extending southeast from the town of Walnut Creek and through Alamo and Danville, is the best route of access. Subsidiary county and township roads bound the region on the south

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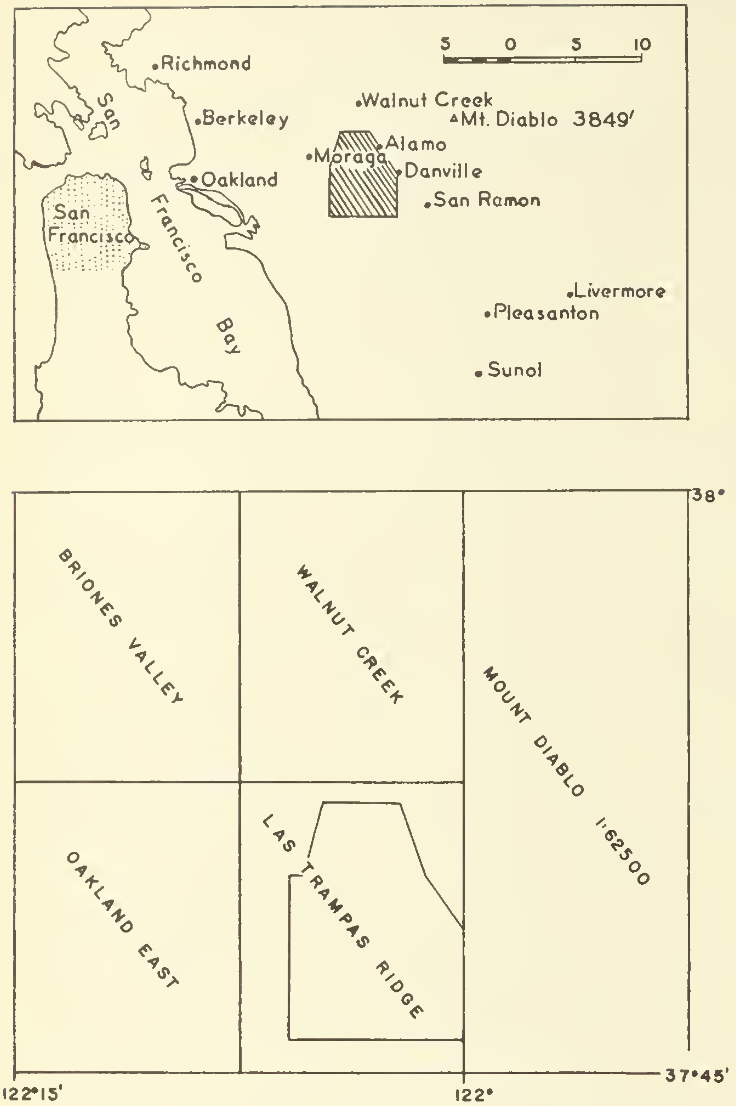

FIGURE 1. Index maps showing location of Las Trampas Ridge area.

and west, and a road-net of East Bay Municipal Utility District's fire trails covers the western half of the quadrangle. The base map used was a U. S. Geological Survey sheet (1:24,000) compiled from aerial coverage (1946) and edited in 1949.

Acknowledgments. It is a pleasure to acknowledge the courtesy and helpfulness of the many residents in the area who permitted access to their property, and to recognize the kind assistance of officials of the East Bay Municipal Utility District. I am particularly indebted to Arthur W. Carlson, Charles Howland, and Sinclair Walbridge, Jr., all of Corduroy Hills Ranch, for the genuine interest and hospitality they extended.

I am especially indebted to N. L. Taliaferro, under whose direction the work was done, to J. Wyatt Durham and R. A. Stirton of the Department of Paleontology, and to F. J. Turner, C. M. Gilbert, and William Mathews of the Department of Geology. Burdette Ogle and other graduate students of the Department of Geology have provided constructive criticism and field discussions.

To the Regents of the University of California, I am highly appreciative for financial assistance during 1949 and 1950.

Previous Work. A. C. Lawson [1] was the pioneer worker in this region. He proposed many of the formational names in use today, and mapped the Concord quadrangle of which the new 7½ minute Las Trampas Ridge sheet is the southeastern quarter. Subsequent stratigraphic work was accomplished by Clark,[2] Trask,[3] Weaver,[4] Kew,[5] and Newton.[6] Newton's study of an adjacent area to the south constitutes a detailed study of the structure that extends into Las Trampas area.

Recent but as yet unpublished mapping in the adjoining Walnut Creek, Briones Valley, and Oakland East quadrangles has been carried on by faculty members and students of the Department of Geology, University of California, in conjunction with undergraduate field courses. Savage, Ogle, and Creely [7] have studied the Pliocene sediments and volcanics immediately to the north and northwest.

Physical Conditions. Elevations range from 225 feet in San Ramon Valley to 2025 feet along the crest of Rocky Ridge. Las Trampas Ridge, somewhat lower than Rocky Ridge, has an average altitude of about 1600 feet. These two ridges comprise the most prominent topographic features of a generally rugged area. They trend northwest parallel to the strike of the bedding. Intermittent streams have deeply incised their courses along the flanks of these ridges, in some places leaving long prominent spurs perpendicular to the regional trend.

Rainfall is usually restricted to the months of November through April. Mean annual precipitation is 15-17 inches along Rocky and Las Trampas Ridges. Rainfall and temperature conditions are those of a mediterranean-type climate.

Physiography. The physiographic development of Las Trampas Ridge area is, in general, approaching maturity. Stream cutting is far from uniform, however, and in some places the picture is complicated by structural control. The local radial consequent drainage developed on the highest part of Rocky Ridge is modified by the development of a subsequent pattern, following an increasing adjustment of streams to structure.

The drainage pattern in the northern parts of Las Trampas and Rocky Ridges is consequent to a local uplift, in some places having become entrenched across the resistant units. The radial pattern is bounded by the Sunol fault on the northeast, beyond which trellis drainage is dominant. To the southwest, the main consequent line persists to at least the Upper San Leandro Reservoir. As an example, a majority of the tributaries of Cull Creek drain from the northeast. Here also one sees the typical breaching of anticlines and the preservation of synclinal troughs as prominent summits.

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[1] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), 1914.

[2] Clark, B. L., Fauna of the San Pablo group of middle California: Univ. California Dept. Geol. Sci. Bull., vol. 8, pp. 385-572, 1915.
Clark, B. L., The San Lorenzo series of middle California: Univ. California Dept. Geol. Sci. Bull., vol. 11, pp. 45-234, 1918.

[3] Trask, P. D., The Briones formation of middle California: Univ. California Dept. Geol. Sci. Bull., vol. 13, pp. 133-174, 1922.

[4] Weaver, C. E., Stratigraphy and paleontology of the San Pablo formation in middle California: Univ. California Dept. Geol. Sci. Bull., vol. 5, pp. 243-269, 1909.

[5] Kew, W. S. W., Tertiary echinoids from the San Pablo group: Univ. California, Dept. Geol. Sci. Bull., vol. 8, pp. 365-376, 1915.

[6] Newton, R. J., The geology northwest of Dublin, California, in the vicinity of Divide Ridge: Univ. California, unpub. Master's thesis, 1948.

[7] Savage, D. E., Ogle, B. A., and Creely, R. S., Subdivision of vertebrate-bearing nonmarine Pliocene rocks in west-central Contra Costa County, California: Unpub. paper presented at a meeting of the Geol. Soc. America, Cordilleran Section, Los Angeles 1951.

The dating of the uplift in the area probably corresponds with the period of upward displacement (along the Sunol fault) of an ancestral San Ramon Valley, represented by terrace remains. Two such levels of tilted and dissected terrace remnants are interpreted as postdating the main period of folding and thrusting but antedating final movements on a series of transverse faults cutting Las Trampas Ridge. Evidence for this is as follows: (1) Uplift appears to be restricted to the southwest side of Sunol fault, as terraces are not recognized on the opposite side of San Ramon Valley; (2) Terrace remnants truncate the underlying structure, but appear at different elevations on either side of transverse faults; vertical displacement along the southernmost fault is negligible, thus accounting for no apparent offset of the terrace; (3) Protected portions of the lower terrace still retain an alluvial cover as much as 30 feet thick; (4) Following uplift along the southwest side of Sunol fault, transverse faults cut and displaced the terraces.

Middle to upper Pleistocene vertebrate bones have been found in the alluvium of Stone Valley to the northeast.[8] These horizontal vertebrate-bearing deposits appear to bury the base of Alamo Ridge and other hills between Danville and Walnut Creek. It is probable that during the latter half of the Pleistocene aggradation was intense, following the main period of folding and thrusting. It was at this time, or slightly before, that terraces were cut, most probably forming the ancestral San Ramon Valley. Following this, displacement took place along first the Sunol fault, then late transverse faults. Aggradation has continued to the present day partly burying topographic highs resulting from the main period of diastrophism.

Savage[9] ascribes an Irvingtonian or earlier Pleistocene age to the deposits that have been slightly tilted, and a later Pleistocene age to alluvium that is essentially horizontal; the transverse faulting in Las Trampas Ridge area may, therefore, be as late as middle Pleistocene.

Recent terraces may be seen along Cull Creek and Bolinger Creek as well as along Las Trampas Creek, where a transverse section of the valley shows a shallow concave profile deeply incised by a V-shaped trench. The recency of continued uplift cannot be disputed when considering the incompetency of such terrace deposits and their susceptibility to rapid erosion. Only now is headward erosion commencing.

STRATIGRAPHY

Cretaceous System

In the extreme southwestern part of the area are two lithologic units of probable Upper Cretaceous age. The upper unit consists largely of coarse cobble and boulder conglomerate of variable thickness, and the lower solely of micaceous sandstone and thin-bedded shale. No fossils were found in either unit, and the age is assigned on the basis of stratigraphic position and lithologic similarity to rocks of Upper Cretaceous age in adjoining areas. The designation Chico formation is not used here, the term "Chico" having been so broadly applied since its inception that it no longer has a reasonable stratigraphic significance.[10]

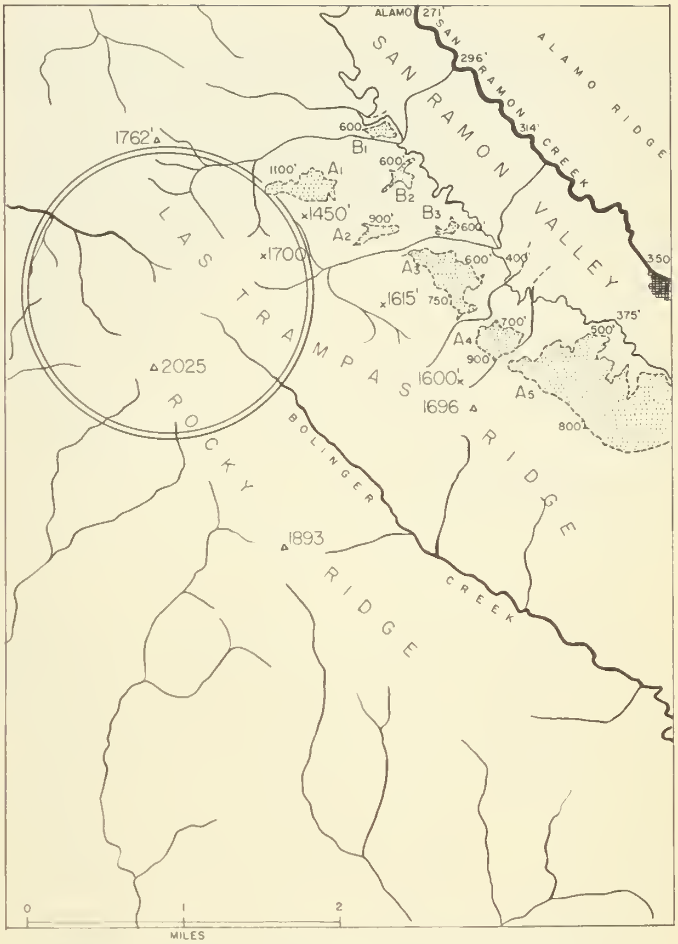

Figure 2. Radial drainage pattern and tilted terraces of Las Trampas Ridge area.

Sandstone and Shale Member. A complete sequence of alternating Upper Cretaceous sands and shales is not found within the area mapped, but a traverse from the Upper San Leandro Reservoir dam to the Miller Creek fault zone yielded a representative section similar in all respects to the succession best exposed along Skyline Boulevard to the west. Thickness of the unit has been estimated as 2,000 to 6,000 feet by Lawson.[11]

The Upper Cretaceous section is made up of micaceous mudstone, in part slightly limy, with interbeds of silt and sandy shale and clay shale. The sandstone ranges from moderately indurated massive beds to bands 2 to 5 inches thick separated by shale laminae approximately an inch wide. These narrow bands of interbedded shale are extremely brecciated and contorted, the result of adjustments taking place between the more competent massive sandstone strata during folding.

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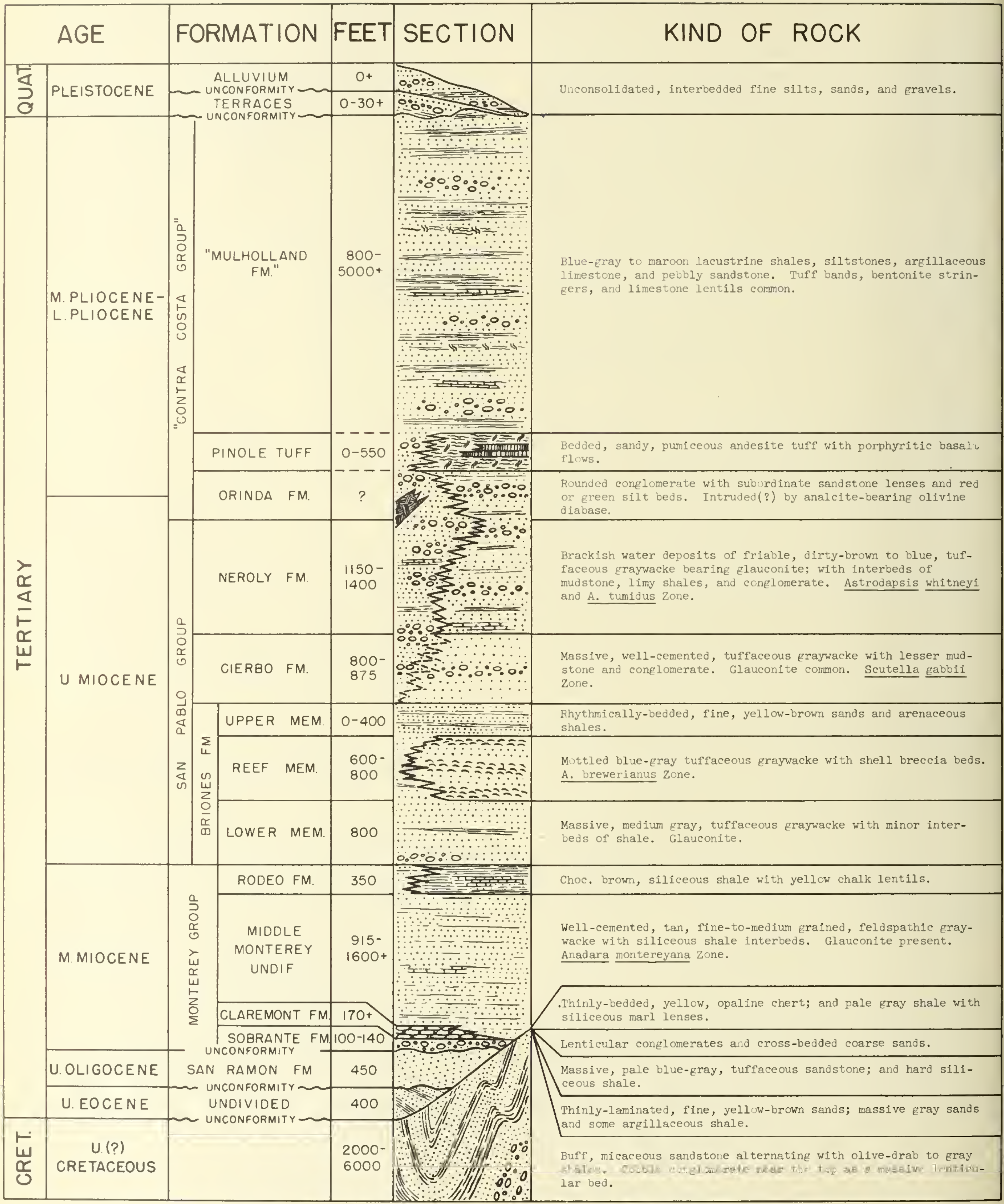
[8] Savage, D. E., Late Cenozoic vertebrates of the San Francisco Bay region: Univ. California Dept. Geol. Sci. Bull., vol. 28, pp. 215-314, 1951.

[9] Savage, D. E., Op. cit.

[10] Taliaferro, N. L., Geologic history and structure of the central Coast Ranges of California: California Div. Mines Bul., 118, pp. 119-162, 1943.

[11] Lawson, A. C., U. S. Geol. Survey Geol. Atlas, San Francisco folio (no. 193), 1914.



GEOLOGIC COLUMN

AGE		FORMATION			FEET	KIND OF ROCK
QUAT.	PLEISTOCENE		ALLUVIUM		0+	Unconsolidated, interbedded fine silts, sands, and gravels.
			UNCONFORMITY			
			TERRACES		0-30+	
			UNCONFORMITY			
TERTIARY	M. PLIOCENE-L. PLIOCENE	"CONTRA COSTA GROUP"	"MULHOLLAND FM."		800-5000+	Blue-gray to maroon lacustrine shales, siltstones, argillaceous limestone, and pebbly sandstone. Tuff bands, bentonite stringers, and limestone lentils common.
			PINOLE TUFF		0-550	Bedded, sandy, pumiceous andesite tuff with porphyritic basalt flows.
			ORINDA FM.		?	Rounded conglomerate with subordinate sandstone lenses and red or green silt beds. Intruded(?) by analcite-bearing olivine diabase.
	U MIOCENE	SAN PABLO GROUP	NEROLY FM.		1150-1400	Brackish water deposits of friable, dirty-brown to blue, tuffaceous graywacke bearing glauconite; with interbeds of mudstone, limy shales, and conglomerate. Astrodapsis whitneyi and A. tumidus Zone.
			CIERBO FM.		800-875	Massive, well-cemented, tuffaceous graywacke with lesser mudstone and conglomerate. Glauconite common. Scutella gabbii Zone.
			BRIONES FM	UPPER MEM.	0-400	Rhythmically-bedded, fine, yellow-brown sands and arenaceous shales.
				REEF MEM.	600-800	Mottled blue-gray tuffaceous graywacke with shell breccia beds. A. brewerianus Zone.
				LOWER MEM.	800	Massive, medium gray, tuffaceous graywacke with minor interbeds of shale. Glauconite.
	M. MIOCENE	MONTEREY GROUP	RODEO FM.		350	Choc. brown, siliceous shale with yellow chalk lentils.
			MIDDLE MONTEREY UNDIF		915-1600+	Well-cemented, tan, fine-to-medium grained, feldspathic graywacke with siliceous shale interbeds. Glauconite present. Anadara montereyana Zone.
			CLAREMONT FM.		170+	Thinly-bedded, yellow, opaline chert; and pale gray shale with siliceous marl lenses.
			SOBRANTE FM.		100-140	Lenticular conglomerates and cross-bedded coarse sands.
			UNCONFORMITY			
	U. OLIGOCENE		SAN RAMON FM		450	Massive, pale blue-gray, tuffaceous sandstone; and hard siliceous shale.
			UNCONFORMITY			
	U. EOCENE		UNDIVIDED		400	Thinly-laminated, fine, yellow-brown sands; massive gray sands and some argillaceous shale.
			UNCONFORMITY			
CRET.	U.(?) CRETACEOUS				2000-6000	Buff, micaceous sandstone alternating with olive-drab to gray shales. Cobble conglomerate near the top as a massive lenticular bed.

Figure 3. Geologic column of Las Trampas Ridge area.

Elsewhere the shale is in uninterrupted thicknesses up to 15 feet and contains a few limestone nodules as well as intercalated argillaceous limestone bands. The shale is brown or dark blue-gray. The sandstone varies from medium gray to brownish-gray on fresh surfaces and commonly contains anastomosing stringers of light-colored calcite. Owing to iron content, the sand weathers to a punky buff-brown. Carbonized wood fragments are found throughout. More massive sands show lineation of micaceous constituents parallel to bedding, and a tendency toward banding.

Slopes are covered by soil and weathered sandstone debris. By tracing this float, it is possible to place fairly accurately the formational boundaries of the Cretaceous rocks and the overlying Monterey chert.

Microscopic examination of heavy and light separations and of thin sections showed that the light fraction contained leached mica, partly altered oligoclase (An_{7-20}), strain-shadowed angular quartz, and rock fragments. Potash feldspar may have been present in appreciable quantities but if so it has been altered to clay. In thin section, green to olive-drab chloritic mica and plagioclase are seen to constitute 40 percent, rock fragments 30 percent, and quartz 15 percent of the recognizable clastic increment; and admixture of fine clayey material and brownish carbonate forms the matrix. Heavy minerals were scarce but included pink garnet, euhedral zircon, brown and blue tourmaline, abundant olive-drab chloritic biotite, glauconite, abundant ilmenite, and lesser amounts of other constituents. This assemblage may have originated from acid plutonics, associated metamorphics, or by reworking of earlier Cretaceous sediments.

Conglomerate Member. The only Cretaceous conglomerate found in the area was adjacent to the spillway of the Upper San Leandro Reservoir dam in the southwest corner of the area mapped. Its maximum thickness ranges from 50 feet immediately south of the spillway to 15 feet a quarter of a mile along strike to the north. The firmly cemented conglomerate maintains a topographic high flanking the eastern side of the reservoir and extending into the Hayward quadrangle.

The conglomerate is markedly dissimilar to overlying Tertiary conglomerates. It consists of massive, lenticular beds of well-rounded cobbles and boulders that are best exposed in the abandoned quarry at the end of Miller Road. In this quarry blasting was necessary to break up the cobble aggregates. Boulders as much as 2 feet in diameter and showing a high degree of sphericity are common. A random count of 3 to 4 inch cobbles yielded: of the dark porphyritic volcanic types, andesite porphyry and basalt; of the acid plutonic types, quartz monzonite, quartz diorite to acid granite, and vein quartz; of the metamorphic types, hornblende schist, biotite schist, biotite gneiss, quartzite, and impure marble. Most of the cementing material is ferric oxide, which imparts a brick-red color to exposures, but some is a brownish carbonate. Coarse, poorly sorted sand and silt fill interstices between the cobbles.

As a source of the detrital material, a slowly rising, low-lying land area to the west has been suggested by Taliaferro.[12] This peninsular or island mass probably was composed of acid plutonic rocks, a roof cover of metamorphic rocks, and some Cretaceous sediments. Darrow [13] in his work on the Montara Mountain quadrangle, has described plutonic rocks ranging from quartz diorite to acid granite. Cretaceous sandstone cobbles found in the lenticular conglomerate herein described indicate possible crustal disturbance during the Upper Cretaceous. Typical Franciscan debris is lacking in this area. The strong lithologic similarity between the Upper Cretaceous detritus and the San Francisco peninsula's older rock units suggest that the major source area lay to the west.

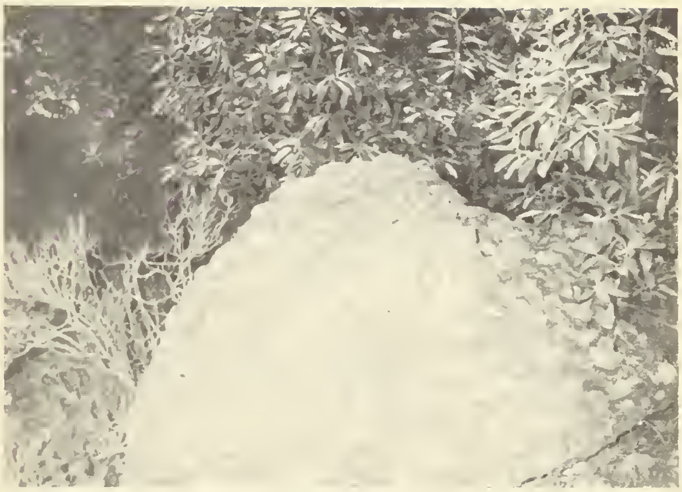


Figure 4. Well-cemented Cretaceous pebble-boulder conglomerate near spillway of Upper San Leandro Reservoir, showing high degree of rounding of the cobbles.

The deposits accumulated in a slowly subsiding local marine basin. Of the periodic changes in deposition, Lawson [14] says, "conglomerate represents an abrupt change in deposition with elevation and consequent erosion and encroachment of deltas of high grade streams upon a marine basin of deposition".

The age designation of these units rests wholly on their stratigraphic position and lithologic similarities to Upper Cretaceous rocks in adjoining areas. Beds near Berkeley contain *Inoceramus sp.* and *Baculites sp.* An uncoiled ammonite has been collected by Peck [15] from black shales in the northern part of the Hayward quadrangle. The ammonite suggests Upper Cretaceous as the age of the beds.

Tertiary System

Upper Eocene

Exposures of Eocene rocks are exceedingly poor, being limited to an area adjacent to Franklin fault. Here, 400 feet of badly sheared, thinly laminated yellow-brown, fine sands with calcite stringers are found, containing *Nitadarenus sp.* and *Cancellaria sp.*, which fall within the limits of the Eocene. These rocks are overlain by Oligocene sandstone in what may be an unconformable relationship. The base of the Eocene section is cut by the Franklin fault.

B. L. Clark [16] describes a section 2 miles south of Walnut Creek as follows:

San Ramon formation
---------------- unconformity ----------------
Fine yellowish-brown sandstone
Hard massive calcareous gray sandstone
Shaly sandstone and soft argillaceous shale
---------------- fault ----------------

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[12] Taliaferro, N. L., Op. cit.

[13] Darrow, R. L., The geology of the northwest part of the Montara quadrangle, California: Univ. California, unpub. Master's thesis, 1951.

[14] Lawson, A. C., Op. cit.

[15] Peck, J., Oral communication.

[16] Clark, B. L., The San Lorenzo series of middle California: Univ. California Dept. Geol. Sci. Bull., vol. 11, pp. 45-234, 1918.

The Eocene age was ascribed to the rocks lying below the San Ramon formation mainly on lithologic similarities and stratigraphic position, as seen in a more complete section to the north.

San Ramon Formation

Prior to 1918, the San Ramon formation was included in the basal Monterey.[17] Clark was the first to recognize it on the west side of San Ramon syncline, where he measured the following 523-foot section:

Monterey formation	
disconformity	
Fine light-gray sandstone	210 feet
Hard siliceous gray shale	20 feet
Fine gray tuffaceous sand with calcareous gray sandstone lentils	290 feet
Coarse gray tuffaceous sand	3 feet
probable unconformity	

At Castle Hill, however, the total thickness is 400 feet. This may indicate that the formation has been subjected to less erosion at the type section.

The only exposures of the San Ramon formation in Las Trampas Ridge area overlie with probable unconformity the Eocene section east of Franklin fault. They in turn are overlain unconformably by lower Monterey strata (the *Arca montereyana* zone). The line of contact with the lower Monterey beds is marked by shallow erosion trenches filled by pebble conglomerate and coarse sand. Except at the upper contact, exposures are poor. The San Ramon forms areas of low relief because it is easily eroded. In Las Trampas Ridge area the formation consists of massive, well-sorted, medium-grained pale blue-gray tuffaceous sandstone and hard siliceous gray shale. In places, carbonate-cemented deep-gray concretionary beds are immediately above leached fossiliferous sand.

Light and heavy mineral separations yielded an abundance of jagged hypersthene and augite grains, some basaltic hornblende, abundant pitted glass, and plagioclase ranging from oligoclase to andesine. Some potash feldspar (sanidine) and abundant quartz were also noted. Part of the quartz may have been detrital; some of the quartz and some of the other minerals may have been derived from ash showers of dacitic or andesitic composition.

Considerable confusion exists today regarding the age of the San Ramon formation. Clark assigned it an Oligocene age; Kleinpell,[18] in correlating micro- and megafossils, stated that it is about basal Zemorrian in age. Durham [19] tentatively correlates the zone containing the San Ramon fauna with the *Echinophoria apta* zone of the uppermost Blakeley formation of Washington. The Western Cenozoic Subcommittee [20] places the San Ramon formation of the Martinez area in the upper Refugian and lower Zemorrian stages. This corresponds to Oligocene-Miocene age. The formation on the south side of Mount Diablo is placed in the somewhat lower *Echinophoria apta* zone.

Among the megafossils collected in the Castle Hill exposures was an *Echinophoria apta*, the first reported from California. This was located 5 inches from the unconformably overlying Monterey at locality 25. On the basis of fauna, the San Ramon formation of this area is placed in the uppermost Oligocene, or in Durham's *Echinophoria apta* zone. Also present are *Thais packi, Dosinia mathewsoni*, and *Polenices sp.*

Monterey Formation

Lawson [21] was the first to subdivide the Monterey group of the San Francisco Bay area into the following seven units: Sobrante sandstone, Claremont shale, Oursan sandstone, Tice shale, Hambre sandstone, Rodeo shale, and Briones sandstone. In subsequent faunal work by Trask [22] the Briones sand has been placed with the San Pablo group.

Within the area mapped, outcrops of the Monterey group are poor, being restricted to roadcuts. A fourfold division of the formation was made on the basis of lithology. The complete section, although not present at any one locality, includes the following conformable members: Sobrante sandstone, Claremont chert, undifferentiated middle Monterey (which includes equivalents of the Oursan, Tice, and Hambre members), and the Rodeo shale. The persistency of the Rodeo shale member was helpful in determining the complex structural relationships of Las Trampas Ridge.

Sobrante Member. The Sobrante member was not recognized in the Monterey exposures of the southwest part of the area, where the Claremont chert rests with angular unconformity on the underlying Upper Cretaceous.

The Sobrante formation described by Lawson in the area 2 miles south of Walnut Creek has been shown to be Oligocene by Clark,[23] but the name has been retained in a restricted sense for the overlying disconformable basal conglomerate and sandstone of the Monterey. Mapping has substantiated the presence of the conglomerate in a narrow strike ridge in the vicinity of Castle Hill. The member measures 140 feet in thickness. To the north the coarser units thin to 100 feet, and to the south they are cut out by the Franklin fault.

A source area containing rocks of varied lithology contributed to the Sobrante sediments. Franciscan material was eroded, possibly as a result of the unroofing of a source that was to become more extensively exposed through the upper Miocene and Pliocene. Bedded lenticular conglomerate as much as 15 feet thick, and coarse-grained, poorly sorted, moderately cemented, cross-bedded sandstone grade upward into siliceous shale. The shale is assumed to be Tice but is not differentiated as such. The conglomerate contains acid plutonic rocks, white quartzite, pale-green chert, plagioclase andesite, purple chert, gray marble, dark gray-green quartzite, red chert veined by quartz, red slate, and buff sandstone (Cretaceous?).

Claremont Member. The Monterey chert and shale locally known as the Claremont member overlap unconformably the Upper Cretaceous sediments in the south-

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[17] Lawson, A. C., Op. cit.

[18] Kleinpell, R. M., Miocene stratigraphy of California, Am. Assoc. Petroleum Geologists, 450 pp. 1938.

[19] Durham, J. W., Megafaunal zones of the Oligocene of northwestern Washington: Univ. California Dept. Geol. Sci. Bull., vol. 27, pp. 101-212, 1944.

[20] Weaver, C. E., et al., Correlation of the marine Cenozoic formations of western North America: Geol. Soc. America Bull., vol. 55, chart 11, pp. 569-598, 1944.

[21] Lawson, A. C., Op. cit., 1914.
Lawson, A. C., and Palache, C., The Berkeley Hills, a detail of Coast Range geology: Univ. California, Dept. Geology Bull., vol. 2, pp. 349-450, 1902.

[22] Op. cit.

[23] Clark, B. L., Op. cit., 1918.

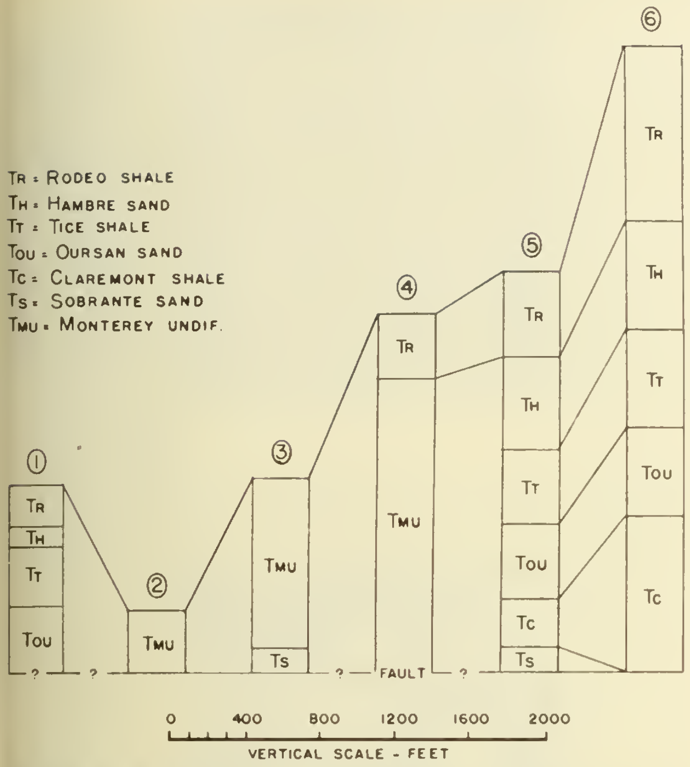

FIGURE 5. Measured sections of the Monterey formation west and southwest of Mount Diablo. (*1*) Lafayette Oil Co., "Morris No. 1"; sec. 28, T. 1 N., R. 2 W., Concord quadrangle, 200 ft. from north side of highway between Lafayette and Walnut Creek. Elev. 405 ft. Total depth 1580 ft. Drilled and abandoned in 1941. (*2*) Tassajara Oil Corp., 2510 ft. south and 1004 ft. west of northeast corner sec. 9, T. 2 S., R. 1 E., Mount Diablo quadrangle. Elev. 317 ft. Spud 11-12-39. Total depth 9777 ft. (*3*) Castle Hill, measured section. Sec. 11, T. 1 S., R. 2 W., Las Trampas Ridge quadrangle. (*4*) Las Trampas anticline, off cross-section C-C″. Secs. 14, 15, T. 1 S., R. 2 W., Las Trampas Ridge quadrangle. (*5*) Crow Canyon, section measured by Newton (1948). Hayward quadrangle. (*6*) Pleasanton quadrangle, section measured by Erickson (1947).

west corner of the area. Areal distribution of the Claremont is limited to this corner of the quadrangle. It is cut to the northeast by the Miller Creek fault. The member has an approximate thickness of 170 feet, but much has been eroded. Newton[24] measured a complete section of the chert 225 feet thick to the south of Las Trampas Ridge area.

The Claremont member consists of chert and some shale with siliceous limy lenses. The shale weathers to a light gray color. On fresh surfaces the color is buff. This silty shale occurs in most places as fissile ¼- to 1½-inch bands between the chert, but in some places as massive 5- to 8-foot beds. The limestone is blue-gray on fresh surfaces; it, too, weathers to a buff color. Anastomosing stringers of calcite run through the jointed, fine-grained limestone. Beds are lenticular and commonly range from 8 to 12 inches in thickness. The chert occurs in 2- to 6-inch beds separated by the shale and limestone, and is folded into a series of tight flexures, due in part perhaps, to submarine sliding of silica gel concentrations laid down in relatively deep basins. The mechanism of sliding is thought to have been aided by interbeds or interlaminations of shale. The chert as seen beneath the microscope is minutely banded, slightly arenaceous opaline material with a few chalcedony inclusions. It weathers to a gray-white color, iron stained, and shows some sulfur on joint surfaces. Where fresh it appears slightly darker and verges on a yellow-ochre or olive color. A characteristic megascopic feature of the chert is the well developed color laminae, which appears as alternating bands 1 millimeter to 2 millimeters thick of yellow, white, and olive color.

Undifferentiated Middle Monterey Beds. The bulk of the middle Monterey unit has been grouped together as "undifferentiated middle Monterey" because of the general paucity of outcrops. Included within this grouping are the probable eastern extension of the Claremont, Oursan sandstone, Tice shale, and Hambre sandstone members. The base of the distinctive and conformable Rodeo member terminates the succession. Exposures are best in the vicinity of Castle Hill where the Rodeo shale is absent. Elsewhere, undifferentiated middle Monterey rocks are poorly exposed along the core of Las Trampas anticline. Here the overlying Rodeo beds were used to delineate structure. To the southwest, pod-shaped undifferentiated sandstone and shale, conformably overlying the Claremont member, are cut by the Miller Creek fault.

Thickness of the undifferentiated middle Monterey strata varies from 915 feet on the east side of Franklin fault to 1600 feet on Las Trampas anticline, where the basal Sobrante member is not exposed. The latter figure compares with Newton's measurement of 1565 feet for similar units along the Crow Canyon road in the Hayward quadrangle.

Fossiliferous, well-cemented, pale-tan, pebbly, feldspathic graywacke with interbeds of sandy shale overlies the Claremont member to the southwest. Microscopic analysis of thin sections showed a poorly sorted graywacke with angular rock fragments, 40 percent; plagioclase 30 percent; quartz 10 percent; all set in a clay-chlorite-like matrix. Grains showing undulatory extinction and a 2V up to 10° probably are strained plutonic quartz. Franciscan microporphyry (spilite basalt?) and much chert are the dominant rock fragments. Glaucophane, euhedral zircon, and as much as 1 percent glauconite are conspicuous in the heavy mineral increment.

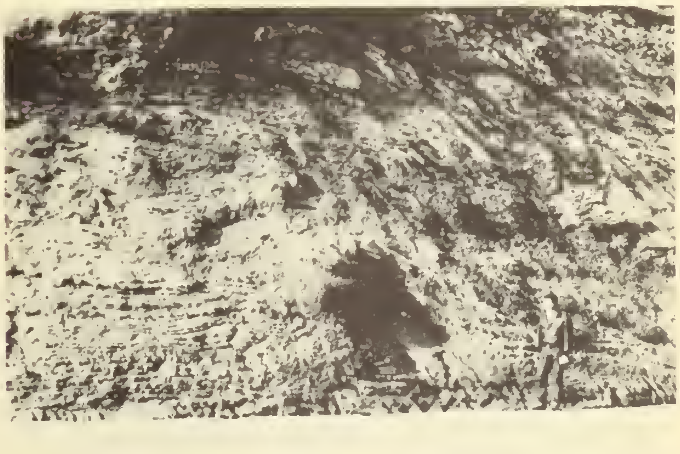

FIGURE 6. Undulating opaline chert of the Claremont member, as seen along Redwood road.

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[24] Newton, R. J., Op. cit., 1948.

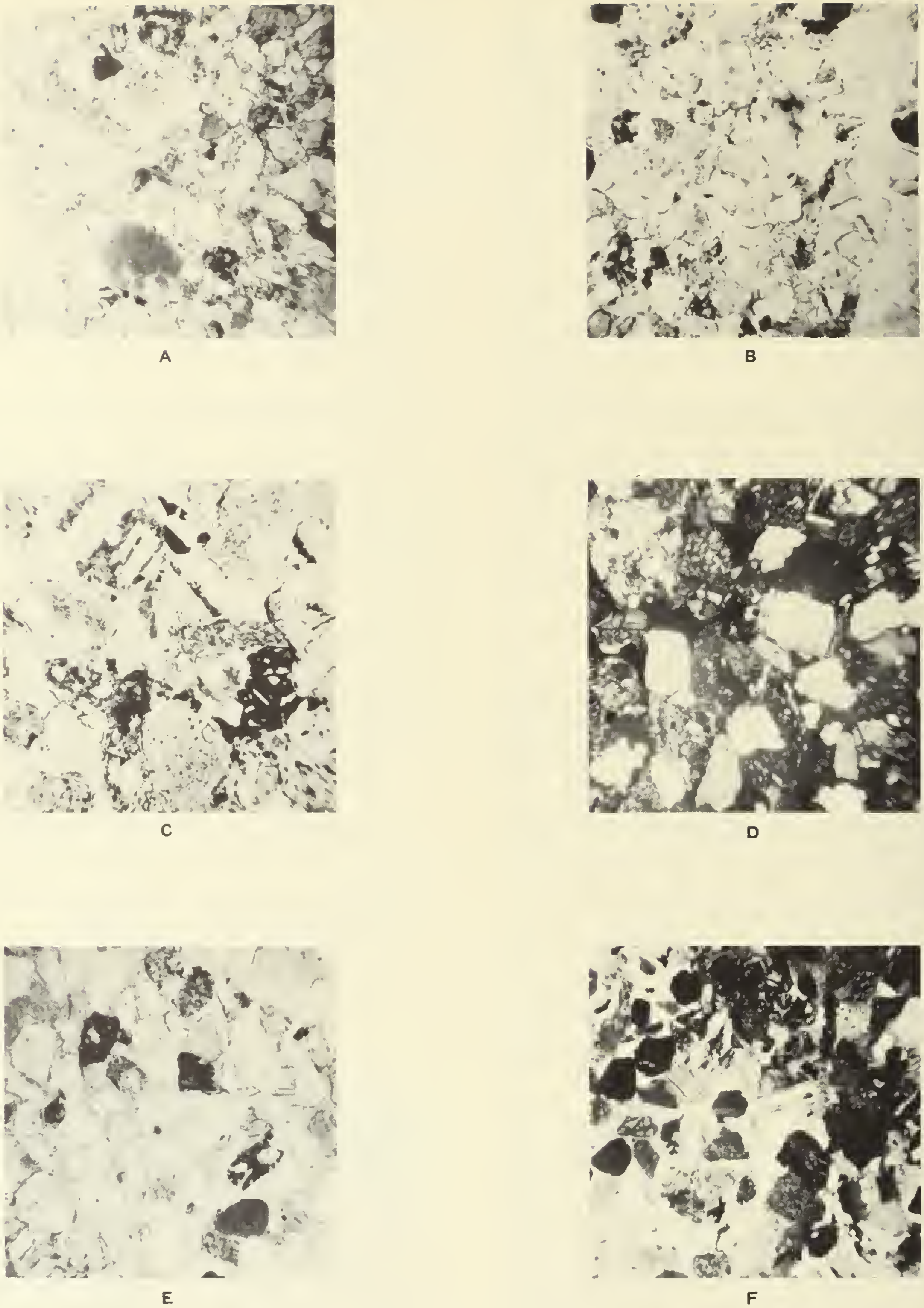

FIGURE 7. Photomicrographs of typical graywackes of the San Pablo group. Magnification 60x. (*A*) Plane polarized light. Glauconitic graywacke composed of angular feldspar, quartz, and lithic fragments set in a clay to chlorite matrix. Large rounded glauconite just below center. (*B*) Chlorite-cemented graywacke from the Cierbo of Rocky Ridge. Cloudy rim about individual grains in center of photo is pale green chlorite cement. Plane polarized light. (*C*) Plane polarized light. Graywacke composed of lithic fragments for the most part. Note abundance of dark microporphyry. (*D*) Crossed nicols. Graywacke showing a diversity of constituents. Microcline at right center, quartzite aggregate in upper left corner. Light constituents are angular quartz and plagioclase. (*E*) Plane polarized light. Glauconitic graywacke sampled from Briones in proximity to shell breccia beds. Anthigenic carbonate cement is seen as striated material of moderate relief filling intergranular spaces. Rounded glauconite at lower right. (*F*) Crossed nicols. Carbonate cemented graywacke from Briones showing a concentration of labile constituents caused by panning effects of near-shore currents, a process seen along present-day beaches. Black grains are magnetite; angite and plagioclase appear at the center.

Undifferentiated middle Monterey rocks of Las Trampas anticline and Castle Hill are composed mainly of brecciated, pale-gray, siliceous shale, in part sulfate-stained, and interbedded, massive, fine-grained graywacke. Some thinly bedded, tan, friable, slightly tuffaceous sandstone is also present, and commonly contains lentils of olive-drab to dark-gray arenaceous limestone. Characteristic of the sandstone is a slightly glauconitic graywacke made up of angular rock fragments, acicular quartz, and plagioclase set in a clayey carbonate matrix. Again, chert and dark microporphyritic basalt dominate the rock fragments. Hornblende is abundant in the heavy mineral fraction. Glass, potash feldspar, and much oligoclase in the light fraction indicate that the rock is either wind-blown acid tuff, or formed by erosion of an acid volcanic source.

Rodeo Member. Well-defined Rodeo beds conformably overlie the undifferentiated middle Monterey units along the length of faulted Las Trampas anticline. The Rodeo shale has been eroded from the uplifted western side of Miller Creek fault. Newton[25] recognized the member to the south along Crow Canyon road, where the fault passes into tight folds. An argillaceous, fine-grained sandstone in contact with the basal Briones member may represent the Rodeo beds east of Franklin fault. However, an erosional disconformity between Monterey sandstone and basal Briones here is regarded as a Hambre-Briones relationship, the Rodeo having been eroded.

The average thickness of the Rodeo member in Las Trampas anticline is 350 feet, rather than 465 feet as seen along the Crow Canyon road.

The Rodeo member is composed of chocolate-brown, argillaceous to siliceous, ferruginous shale. Weathering red-brown, the shale is compact, tough, and usually massive, but may be in 3- to 5-inch partly fissile beds. The member coarsens toward the base and grades into the underlying Hambre sandstone. The conformably overlying Briones member is a coarse-grained graywacke. The central part of the Rodeo member, a siliceous shale, carries foraminiferal casts, none of which could be accurately identified. Three horizons of lenticular, yellow, chalky limestone as much as 7 feet in thickness persist throughout the member.

The Monterey sandstone of this area yielded a fauna of middle Miocene age, equivalent in part to fauna from the rocks of the Temblor found to the south. Kleinpell,[26] on the basis of foraminifera, placed the unit within the limits of the basal Relizian through basal Mohnian stages, including the *Bruclarkia barkeriana* through *Arca montereyana* zones. Newton[27] identified *Arca devincta* from the Sobrante member, and *Bruclarkia oregonensis* from the Oursan member in the Hayward quadrangle. These members he considered to be of the same age as the *Turritella ocoyana* zone of the Temblor formation.

Near Miller Creek fault *Chione temblorensis*, *Pecten andersoni*, and *Dosinia mathewsoni*, found in the sandstone overlying the Claremont member, indicate that it is a correlative of the Temblor. *Anadara devincta montereyana*, found in Las Trampas anticline is also found in the upper part of the Temblor formation. The Sobrante member of Castle Hill area yielded abundant *Ostrea titan*, and a few *Anadara montereyana*.

The complete megafossil assemblage for this area consists of *Yoldia cf. cooperi*, *Tivela inezana*, *Dosinia mathewsoni*, *Pecten andersoni*, *Clementia sp.*, *Amiantis sp.*, *Pachydesma sp.*, *Chione temblorensis*, *Anadara devincta montereyana*, *Tagelus sp.*, *Cardium californiense*, *Ostrea titan*, *Lucina sp.*, and *Spisula sp.*

Oscillatory movements during the period of Monterey marine sedimentation may account for the divergent rock types. A small basin of deposition, progressively shallower to the east, can be shown by the correlation between known stratigraphic sections as measured in adjacent quadrangles to the north, east, and south, as well as within the area mapped.

San Pablo Group

Lawson[28] and Weaver[29] were among the first to make a reconnaissance of the San Pablo formation in the bay area. They did not separate the Briones formation from the Monterey, but regarded it as a member of the Monterey formation. Trask[30] in subsequent study of the Briones beds, noted its close faunal affinity to the overlying San Pablo, and concluded that there were three minor marine epochs following the deposition of the Monterey beds, during which the Briones, Cierbo, and upper San Pablo (equivalent to Santa Margarita or Neroly) beds were laid down. Clark[31] proposed the name Neroly formation to replace Santa Margarita and incorporated the Briones beds in his San Pablo group on paleontologic and lithologic grounds. Weaver[32] included within the San Pablo group the Briones sandstone, Cierbo sandstone, and Neroly formation.

The San Pablo group in Las Trampas Ridge area is divided into five units: the Briones formation includes three of the units—a lower massive sand member, a middle shell bed or reef member, and an upper sandstone member; the Cierbo formation is massive sandstone; and the Neroly formation is composed of friable tuffaceous sandstone and mudstone and some conglomeratic interbeds. Where members are not clearly distinguishable the rocks have been classed as either Briones formation or upper San Pablo undifferentiated.

The San Pablo group crops out in approximately one-third of the mapped area. It is absent to the southwest in the vicinity of Miller Creek fault. Good exposures are on the precipitous flanks of Rocky Ridge where the steeply inclined to overturned upper four members of the group are faulted against continental deposits of late upper Miocene or early Pliocene age. Poorer exposures are found along the length and breadth of the faulted Las Trampas anticline, and the Tice Valley syncline. In the Tice Valley syncline, beneath the middle Pliocene Pinole tuff, an incomplete but well-exposed section consists of dominantly tuffaceous blue sandstone.

Although the thickness of members along Rocky Ridge is for the most part uniform, considerable variations exist elsewhere. For example, on the southeast extremity of

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[25] Newton, R. J., Op. cit., 1948.

[26] Kleinpell, R. M., Op. cit. 1938.

[27] Newton, R. J., Op. cit., 1948.

[28] Lawson, A. C., and Palache, C., The Berkeley Hills, a detail of Coast Range geology: Univ. California Dept. Geology Bull., vol. 2, pp. 349-450, 1902.

[29] Weaver, C. E., Op. cit. 1909.

[30] Trask, P. D., Op. cit., 1922.

[31] Clark, B. L., The marine Tertiary of the west coast of the United States: Its sequence, paleogeography, and the problems of correlation: Jour. Geology, vol. 29, pp. 583-614, 1921.

[32] Weaver, C. E., et al., Correlation of the marine Cenozoic formations of western North America: Geol. Soc. America. Bull., vol. 55, chart no. 11, pp. 569-598, 1944.

Representative measured sections, San Pablo group.

Unit	Rocky Ridge		Las Trampas Ridge	Tice Valley
	Section D-D′ (thickness in feet)	Section F-F′ (thickness in feet)	Section E-E′ (thickness in feet)	Section A-A′ (thickness in feet)
Neroly	1400	1150	1100	1125
Cierbo	800	875	-------	-------
Upper Briones	380	400	225	-------
Middle Briones	750	600	800	800
Lower Briones	fault	fault	800	fault
Total	3330	3025	2925	1925

Las Trampas Ridge the combined Cierbo-Neroly measures but 450 feet, whereas it measures 2025 feet at the southeast end of Rocky Ridge.

The San Pablo sandstone units are mostly poorly sorted, silty, medium- to coarse-grained graywacke, but partly fine-grained silty graywacke. (See fig. 20, page 26.)

Lithology. The lower Briones sandstone member of the San Pablo group lies conformably on Rodeo shale in all exposures save in the vicinity of Castle Hill. Here the Rodeo member has been eroded, and the basal Briones sediments have filled erosion gutters in the Hambre member. The basal Briones member grades upward into the coarser middle reef member. The lower Briones beds consist of massive greenish-gray tuffaceous graywacke that weathers to shades of brown. Some beds measure as much as 75 feet in thickness. The graywacke is composed of angular, poorly sorted medium- to coarse-grained feldspar and dark lithic fragments. The fragments impart a salt-and-pepper appearance to outcrops. Thin, dark-colored shale partings and concretions are common in some massive beds. Elsewhere, rounded shale inclusions up to half an inch in diameter are abundant in the sandstone. Platy graywacke beds 2 to 10 inches thick, having bleached mica along bedding surfaces, are not uncommon.

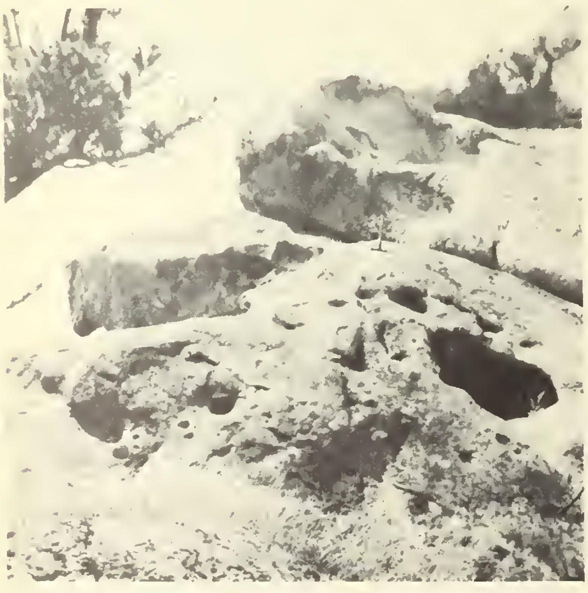

FIGURE 8. Massive Cierbo graywacke near the crest of Rocky Ridge, showing common erosion cavities.

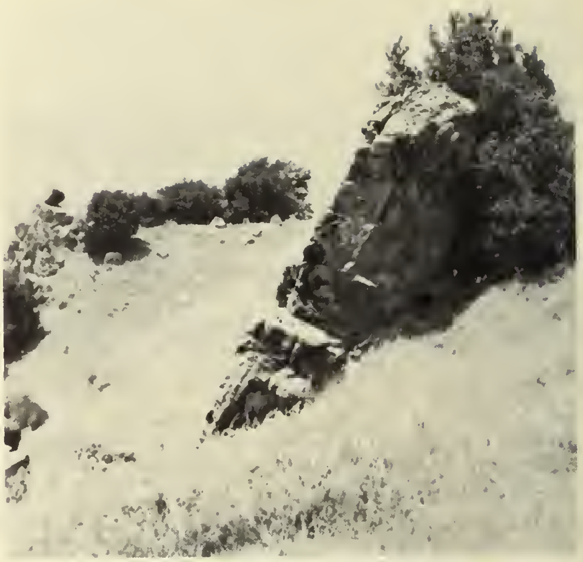

FIGURE 9. Cierbo graywacke in the typical mode of outcrop on Rocky Ridge.

The middle Briones reef, or shell-breccia member, constitutes the most resistant unit in the area. It sustains the topographic highs of Rocky and Las Trampas Ridges, cropping out as continuous rock walls along the summits. The overlying and underlying contacts are gradational. The middle Briones member is coarse-grained, poorly sorted, mottled, blue-gray graywacke cemented by carbonate. In three zones on Rocky Ridge are pebbly shell breccia beds as much as 10 feet thick composed of pelecypod debris and *Astrodapsis brewerianus* tests. The pebbles consist of red and black chert, quartz, and andesite porphyry. These near-shore shell beds vary in thickness; in some places they diminish in number, and in other places are absent. They are more firmly cemented than the 30- to 40-foot massive interbeds. On Rocky Ridge *Astrodapsis brewerianus* is restricted to the two lowermost shell beds, whereas in the vicinity of Las Trampas peak only the upper reef carries this distinctive form.

The upper Briones member, which was not recognized over much of Las Trampas Ridge, is an incompetent unit controlling erosion of a chain of small consequent valleys near the crest of Rocky Ridge. It grades into the overlying Cierbo. Conchoidally fracturing, pale yellow-brown, moderately fossiliferous, 5- to 7-foot beds of micaceous, fine-grained sandstone are rhythmically interbedded with 2-foot beds of arenaceous shale. The sandstone, which carries some shale pellets, is concretionary at its base and slightly pebbly at its contact with the Cierbo.

Weather-resistant massive beds of the Cierbo member are best exposed along Rocky Ridge as six spectacular, near vertical hogbacks extending as much as 50 feet above the adjoining ground level. Other exposures are on the flanks of Las Trampas anticline and in the Tice Valley syncline. Blue tuffaceous graywacke is most abundant in the northern third of the area, but it may also be seen just west of San Ramon Valley. A gradational contact separates the Cierbo member from the overlying Neroly beds.

The well-cemented, heterogeneous sandstone of the Rocky Ridge section is graywacke in the true sense of the

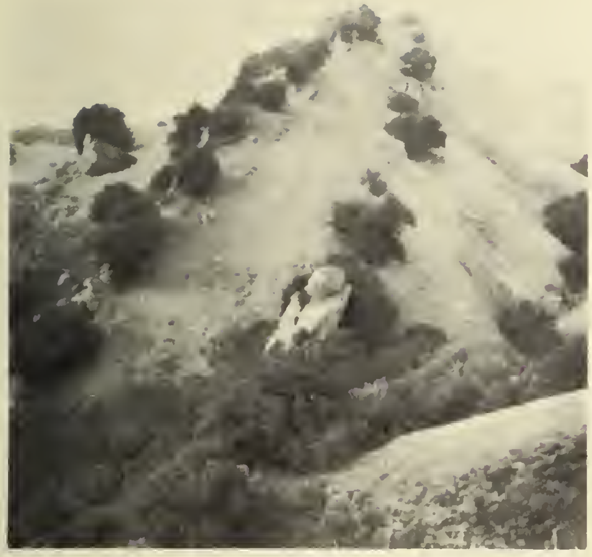

Figure 10. Massive Cierbo graywacke outcropping as a hogback on the summit of Rocky Ridge. Concealed unit to right of center is upper Briones. View toward the northwest.

term as used by Edwards[33] and Pettijohn.[34] The base of the Cierbo here is marked by a discontinuous pebble conglomerate up to 3 feet thick incorporated in a mottled medium-gray, rarely fossiliferous, tuffaceous graywacke. As in the Briones beds, angular quartz, feldspar, ferromagnesian minerals, and lithic fragments impart a salt-and-pepper appearance to the rock. The graywacke is pitted by cavelike erosion cavities; the weathered rock surface assumes whaleback outlines. Between the massive graywackes are interbeds of brown to tan friable silty mudstone and sandstone yielding leaf impressions. Silicified tree trunks (willow) up to 30 inches in diameter are weathered out of the friable sands. Above the basal graywacke on Rocky Ridge is a pebble conglomerate containing abundant fragments of *Ostrea bourgeoisii*. According to Clark[35] this form is characteristic of the Cierbo in this vicinity, where *Echinarachnius gabbi* and *Astrodapsis cierboensis* are absent. The conglomerate is made up of quartz, green, black, and red chert, and intermediate to basic porphyritic volcanic pebbles as much as 3 inches in diameter, which are well-rounded, and cemented by carbonate minerals.

The Tice Valley section of the Briones member exhibits 50- to 70-foot beds of blue and buff tuffaceous graywacke containing some pebble stringers of chert separated by brown siltstone. Biotite is abundant in the graywacke of the area. In the Cierbo beds of both Las Trampas anticline and Tice Valley, *Echinarachnius gabbi* var. is found near the base.

One mile south of Alamo the relationship between the Cierbo member and the underlying Briones member is well shown by the exposure of a chalk-white biotitic vitric tuff some 3 to 10 feet in thickness, that is interbedded with normal Neroly strata. As the tuff is traced to the southeast, the Cierbo member thins so that the tuff directly overlies the Briones. The same tuff 2½ miles to the northwest lies 550 feet above the Briones. This may indicate that during the time of Cierbo deposition a sea transgressed over a topographic high capped by the Briones member.

The relationship of the Neroly member to the overlying continental deposits cannot be seen in most places. However, in the Tice Valley syncline, friable Neroly sandstone and brackish-water mudstone are overlain by the Pinole tuff in what appears to be a conformable gradational sequence. Elsewhere the tuff is not exposed, so that the undifferentiated Orinda-Mulholland formation appears to overlap the Neroly. In section 26, on the southwest side of Las Trampas Ridge, prominent shell beds of the upper Neroly are overlapped obliquely by pebbly continental sandstone closely resembling sandstone of Pliocene age. On the southwest side of Rocky Ridge in section 12, the depositional character of the upper Neroly beds is shown by erosion trenches, pebbles resembling Neroly rocks, crossbedding, and cut-and-fill. These features may be the result of periodic warping, shallowing of the sea, and elevation of the basin floor.

The Neroly member consists predominantly of massive to well-bedded, friable, poorly sorted, tuffaceous sandstone and interbeds of mudstone, limy shale, and pebble conglomerate. The sandstone is made up of Franciscan and intermediate volcanic debris, feldspar, and angular quartz grains. Some rounded mudstone blebs from the older Neroly beds are in the sandstone. Anastomosing stringers of red-brown iron oxides and gray concretions further distinguish the sandstone from the Cierbo beds beneath. Thinly laminated, color-banded, pale olive shale containing bentonite intercalations 1 inch thick are common in the upper half of the member. The succession is broken by carbonate-cemented pebbly shell beds 4 feet thick, which contain *Mulinia pabloensis* and other well-preserved pelecypods. *Astrodapsis whitneyi* is found at several localities, associated with and below *Astrodapsis tumidus*.

Origin. Several observations may be made concerning the conditions of origin of rocks of the San Pablo

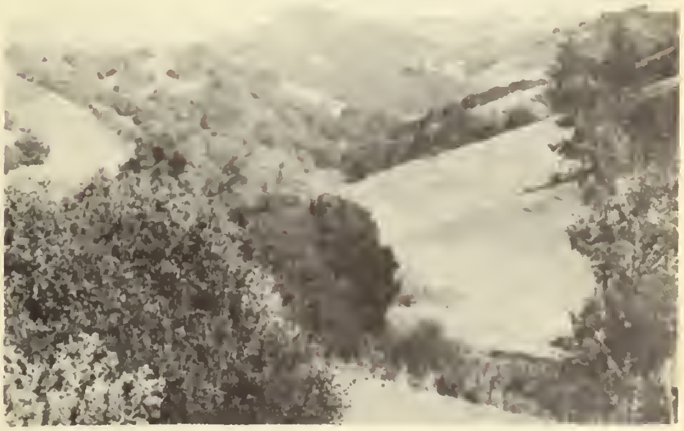

Figure 11. Northwest side of Rocky Ridge. Prominent outcrops in background are Cierbo graywacke.

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[33] Edwards, A. B., The petrology of the Cretaceous greywackes of the Puari Valley Papua: Royal Soc. Victoria, Proc., vol. 60 (new ser.), pp. 163-171, 1947. . . . The petrology of the Miocene sediments of the Aure Trough, Papua: Royal Soc. Victoria Proc., vol. 60 (new ser.), pp. 123-148, 1947.

[34] Pettijohn, F. J., Sedimentary rocks, Harper Brothers, New York, p. 526, 1949.

[35] Clark, B. L., Op. cit. 1915.

group. Unmacerated plant remains, widespread shell beds, and persistent glauconite indicate near-shore marine deposition. The massive character of the sandstone beds, their lithofacies change along strike, and their poor sorting probably indicate rapid discharge of loaded streams into a series of subsiding basins. Warm water is indicated by the fauna, yet chemical decomposition of the most decomposable constituents is negligible. This, along with angularity of quartz, may indicate that mechanical weathering dominated chemical breakdown, and that weathering was followed by rapid erosion, transport, and immediate burial. Intact fossil starfish remains corroborate the idea of rapid sedimentation.

The graywacke was derived from predominantly andesitic rocks, such as easily eroded unconsolidated tuffs, or from airborne ash. Heavy- and light-mineral analyses of representative San Pablo group graywackes are given in the appendix.

Age and Correlation. The San Pablo group is correlated with rocks deposited during the later two-thirds of the Mohnian stage and through the earlier half of the Delmontian stage, according to Kleinpell.[36] Weaver et al.[37] placed the group within the limits of the Luisian stage through the Delmontian stage, and recognized the following three zones based on metazoans: Briones, *Astrodapsis brewerianus* zone; Cierbo, *Echinarachnius gabbi* zone; and Neroly, *Astrodapsis tumidus* zone. The group therefore is upper Miocene and possibly lower Pliocene.

Pecten andersoni gonicostus is common in lower Briones sandstone and occupies a similar stratigraphic position in the section at San Pablo Bay. This form has not been recorded except from San Pablo Bay. *Pecten raymondi brionianus* is abundant below the *Astrodapsis brewerianus* zone (middle Briones). Tests of *Astrodapsis brewerianus* in places comprise reef beds over the entire area, and are the most persistent index fossils of the group. *Nassarius whitneyi* and *Pecten andersoni* are characteristic of the fine-grained sandstone beds lying above the shell beds in Rocky Ridge and Las Trampas anticline sections. *Echinarachnius gabbi* var. was not found on Rocky Ridge, so *Ostrea bourgeoisii* is used as the Cierbo marker. The *Echinarachnius gabbi* zone is present in Las Trampas anticline. Finally, *Pecten crassicardo*, *Astrodapsis whitneyi*, and *Astrodapsis tumidus*, representing the *Astrodapsis tumidus* zone, are found in all sections of the Neroly. *Astrodapsis whitneyi* invariably occurs with or below the *Astrodapsis tumidus* zone.

Megafossils from San Pablo group

Briones units
Nassarius whitneyi
Astrodapsis brewerianus
Pecten andersoni
Pecten raymondi brionianus
Pecten andersoni gonicostus
Amiantis sp.
Anadara devincta
Dosinia cf. merriami
Yoldia cooperi
Spisula falcata
Polinices sp.

Cierbo units
Ostrea bourgeoisii
Scutella gabbi var.
Neptunea cierboensis
Calyptraea martini
Spisula sp.

Neroly units
Astrodapsis tumidus
Astrodapsis whitneyi
Pecten crassicardo
Protothaca staleyi
Mulinia pabloensis

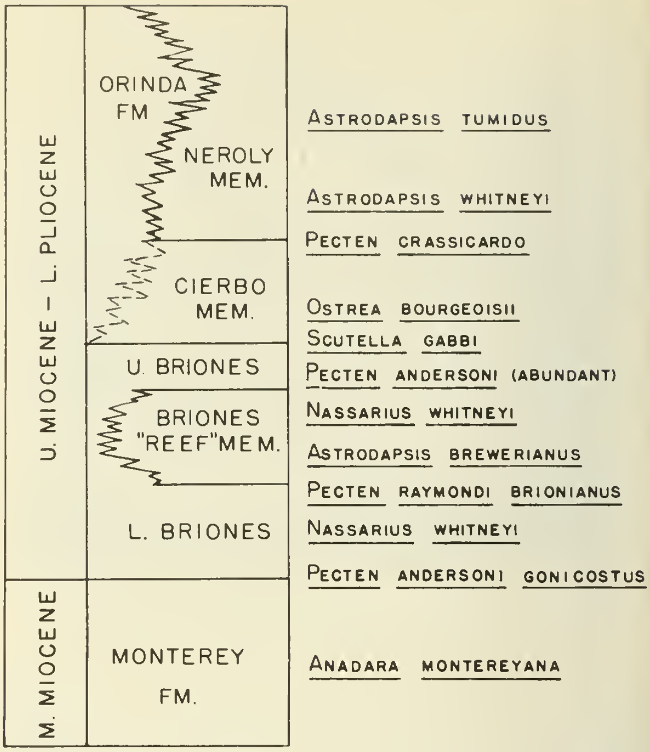

Figure 12. Stratigraphic position of diagnostic megafossils of the San Pablo group.

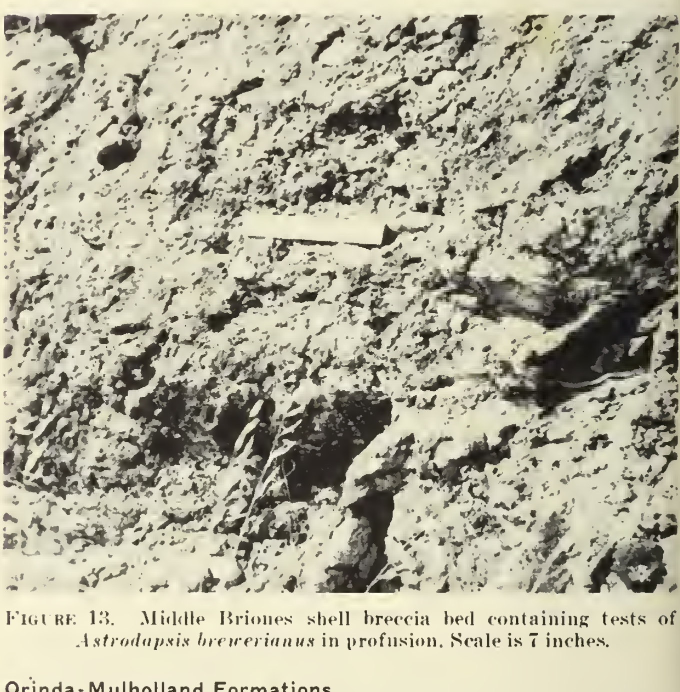

Figure 13. Middle Briones shell breccia bed containing tests of *Astrodapsis brewerianus* in profusion. Scale is 7 inches.

Orinda-Mulholland Formations

Lawson[38] mapped and described the continental deposits within Las Trampas Ridge area as the Orinda formation. Originally Lawson and Palache[39] designated the lower Pliocene silt, sandstone, and conglomerate in the Berkeley Hills as the type Orinda. Subsequent work to the east by Savage and associates[40] has shown the need for a revision of stratigraphic terminology. They suggest reviving the name Contra Costa for a group, to include five distinct formations, the Orinda formation being at the base.

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[36] Kleinpell, R. M., Op. cit., 1948.
[37] Weaver, C. E., et al., Op. cit., 1944.
[38] Op. cit., 1914.
[39] Op. cit., 1902.

Invertebrate studies by Richey,[41] examination of the Mulholland flora by Axelrod,[42] and the vertebrate correlations by Savage[43] indicate an age of uppermost Miocene through middle Pliocene for the proposed Contra Costa group.

Within Las Trampas Ridge area only two of the five formations of the group are recognized, the Grizzly Peak, Siesta, and Bald Peak formations being absent. Along the axis of Kaiser Creek and Tice Valley synclines as well as at the end of Cull Canyon road the Mulholland formation is well exposed. Elsewhere deposits like the Orinda interfinger with and overlap the underlying San Pablo group. The Orinda formation can be seen along the flanks of Las Trampas and Rocky Ridges, its basal beds resembling the brackish-water Neroly member. Where the Mulholland formation overlies the Orinda, rather than the Pinole tuff, efforts to differentiate the two were unsuccessful although the presence of the two formations was determined by lithologic variations and by fossil remains.

Throughout their extent, the Orinda-Mulholland undifferentiated sediments underlie areas of moderate relief and slope. Except for the prominent ridge paralleling the Cull Creek fault, the incompetency of the rocks of the Mulholland unit favors landsliding and rapid erosion. Topographic swales are characteristic and are developed in mudstone and sandstone flanked on either side by more resistant lenticular conglomerate.

Orinda Rocks. The Orinda is predominantly mudstone, silt, dirty cross-bedded sandstone, and intercalated heterogeneous conglomerate. The conglomerate, occurring in beds as much as 40 feet thick, contains subrounded fragments varying from pebble to cobble size, most of which are weathered porphyritic volcanic rock, and Franciscan chert; but some of the pebbles are vein quartz, banded Monterey chert, friable sandstone, peat, acid plutonic rock, glaucophane schist, and other metamorphic rocks. Weathering and deformation has intensely fractured the conglomerate. Beds as much as 24 inches in thickness of gray, green, and red semi-consolidated siltstone, mudstone, and sandstone underlie gentle grassy slopes. Lithification is only local, the cementing materials including iron oxides, carbonate, and clay.

Mulholland Rocks. Excellent exposures of Mulholland rocks are to be seen along the upper reaches of Kaiser and Cull Creeks, which lie on strike with the type locality 7 miles northwest. At the end of Cull Canyon road, blue-gray bedded lacustrine shale, siltstone, argillaceous limestone, and pebbly sand are exposed in a quarry cut. Fossil leaves and fresh-water ostracods are especially abundant here. Ripple marks and cross-bedded microstructure are commonly developed in the sandstone, some strata of which are as much as 10 feet thick. Dark gray to red shales appear as 6-inch to 5-foot thinly laminated interbeds. These beds may be traced with minor facies changes along strike for several miles, being more persistent than the lenticular Orinda units. Along a line extending from the southwest quarter of section 12 to a point just north of Saint Marys College reservoir, similar ripple-marked beds containing a Mulholland flora are well exposed. In section 11, south of this locality, limestone lentils showing algal structure are interpreted as being of lacustrine origin. Elsewhere tuff and bentonite beds less than a foot thick form persistent zones.

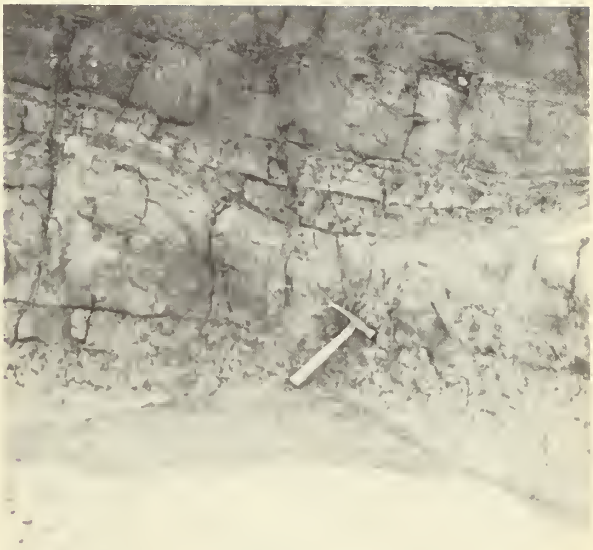

Figure 14. Swayback structure developed from channeling effects within the upper Neroly sands. Southeast extremity of Rocky Ridge.

Conditions of Deposition of the Orinda-Mulholland Rocks. Richey[44] in describing two marine fossil zones in the Orinda beds, stated that in the Berkeley Hills the Orinda probably transcends the space and time boundaries of the marine San Pablo units of the Mount Diablo area. It is quite possible that continental deposits of upper Miocene age exist in the western part of Las Trampas area, for the Cierbo and Neroly members of the San Pablo group are absent.[45] The Orinda beds here directly overlie Briones units conformably. A rising land mass to the west may have caused slow regression of the San Pablo seas to the east and continental deposits were laid over marine sediments. Such an overlap may be seen in sections 23 and 26 where prominent Neroly sands are cut obliquely by the upper Orinda beds. It suggests that a buried Orinda-Cierbo strand-line exists to the southwest of the present Orinda-Neroly contact.

During and after upper Miocene time, but before the middle Pliocene, the Monterey and older formations were uplifted on the west by pulsatory movements, and contributed cobble debris to the Orinda beds. A western source is suggested because (1) the clastic particles involved are similar to rocks existing only to the west, (2) the Orinda formation thickens considerably to the east as if source materials poured into large basins as alluvial fans from the west, and (3) shingling effects of flattened pebbles are so aligned as to denote eastward-flowing

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[40] Savage, D. E., Ogle, B. A., and Creely, R. S., Op. cit.

[41] Richey, K. A., A marine invertebrate fauna from the Orinda, California formation: Univ. California Dept. Geol. Sci. Bull., vol 27, pp. 25-36, 1943.

[42] Axelrod, D. I., The Mulholland flora, California: Carnegie Inst. Wash. Pub. 553, pp. 103-146, 1944.

[43] Op. cit.

[44] Richey, K. A., Op. cit., 1943.

[45] Newton, R. J., Op. cit., 1948.

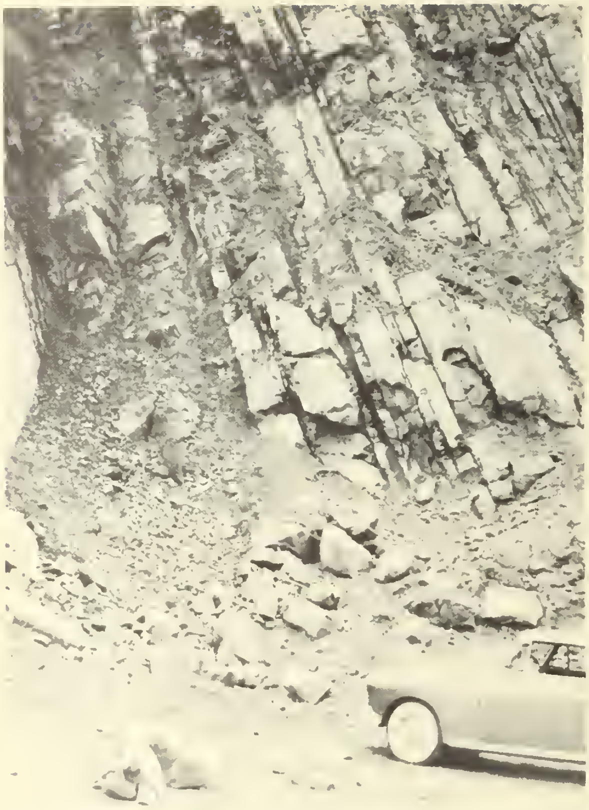

FIGURE 15. Bedded sand and calcareous mudstone of the Mulholland formation of lacustrine origin, in quarry at end of Cull Canyon road.

streams. Pulsatory uplift is indicated by the alternating coarse- and fine-grained clastic sediments resulting from the periodic renewal of strong erosional conditions. An alternative explanation for such rapidly changing conditions of sedimentation is deposition on a flood plain on which the stream occupied different parts of the plain at different times. In either case short transit is implied by the preservation of easily eroded schists and sedimentary material.

Flood-plain conditions ended before middle Pliocene time, and were followed by lacustrine conditions. At the same time, but lower in the stratigraphic succession, the Pinole tuff was deposited over the northeastern portion of the area conformably on, and perhaps gradationally interbedded with, the upper San Pablo beds. Quiet lacustrine conditions for Mulholland deposition are shown by continuous lithofacies, abundant ostracods, freshwater limestone lentils, and the excellent preservation of fossil leaves.

A maximum thickness of 5000 feet is estimated for the combined Orinda and Mulholland formations, from graphic determinations along cross-section E-E′. Thinning of the beds to as little as 800 feet is probable on the southwest.[46]

Age and Correlation. Before discussing age determinations for the undifferentiated Orinda-Mulholland formations, it should be emphasized that discrepancies exist in chronologic terminology as used by paleobotanists, vertebrate paleontologists, and invertebrate paleontologists. Age of the Orinda section has been determined on the basis of vertebrate evidence. University of California vertebrate localities are in Bolinger Canyon and on the western flank of Rocky Ridge. No determinable fossils were found near Miller Creek fault, where the Orinda may be equivalent in age to Cierbo beds of the San Pablo group.

Nannippus tehonensis from Rocky Ridge is indicative of very early Pliocene time, and *Hipparion cf. mohavense* in Bolinger Canyon is characteristic of the Siesta beds. According to Stirton [47]

> . . . The Orinda and Neroly vertebrates from the Bay region may be correlated with those from the lower Chanac (interbedded with "Santa Margarita") and possibly from lower Mint Canyon. The characteristic Lower Pliocene species from the Bay region are *Eucaster lecontei* (Merriam), *Hipparion cf. mohavense*, *Nannippus tehonensis* (Merriam), and *Pliohippus cf. tehonensis*. The first two occur in the Siesta and the other two are in the Orinda (Neroly).

The Pinole tuff has been given a middle Pliocene age on the basis of vertebrate evidence alone. Of these deposits Stirton says

> The Pinole fauna is middle Pliocene in age. It is younger than the Hemphill of Texas and clearly younger than the Orinda or Siesta.

The continental beds found above the Pinole tuff in Tice Valley are similar in all respects to the units found at the end of Cull Canyon road. They are grouped together as the Mulholland formation. At University of California location V3303 in ripple-marked beds just east of Saint Mary's dam site (and along strike from the Cull Canyon section) proboscidean and antilocaprid tracks suggest middle Pliocene age. Recently, a Mastodon atlas as well as numerous leaves of *Salix wildcatensis* (willow) have been found along the northeastern limb of Kaiser Creek syncline. On weak faunal and strong lithologic and stratigraphic evidence it is concluded that the lacustrine beds in the Las Trampas Ridge area correlate with the type Mulholland as recognized by Savage et al.[48]

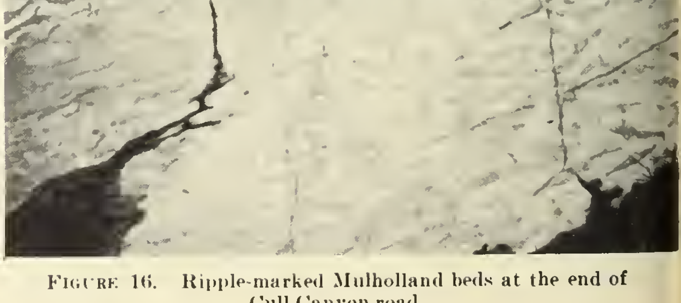

FIGURE 16. Ripple-marked Mulholland beds at the end of Cull Canyon road.

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[46] Newton, R. J., Op. cit., 1948.

[47] Stirton, R. A., Cenozoic mammal remains from the San Francisco Bay region: Univ. California Dept. Geol. Sci. Bull., vol. 24, pp. 339-410, 1939.

[48] Savage, D. E., Ogle, B. A., and Creely, R. S., Op. cit., 1951.

Pinole Tuff

The Pinole tuff is present only in the northern half of Tice Valley syncline where it appears as a continuous pale-gray to chalk-white erosion-resistant formation, bounded below by brackish water marine sands and above by lacustrine Mulholland sediments. Evidence for an unconformable relationship between the three units is lacking. Either the marine sandstones correspond to Orinda, or the Orinda was not deposited here.

Lawson[49] first mapped the areal extent of the tuff. Vitt,[50] however, undertook detailed microscopic work here, as well as at other exposures of Pinole in the bay area. He described the tuff as composed dominantly of pumiceous glass, but containing some mineral and rock fragments, the whole being of andesitic composition. Augite, hypersthene, and oligoclase andesine make up the crystalline fraction.

The Pinole tuff in Tice Valley is roughly divisible into three gradational lithofacies totaling 550 feet in thickness. Sandy tuff beds comprise the lowermost division, which directly overlies, and is in part gradationally interbedded with, marine sands containing an andesite pebble conglomerate. The middle unit is composed of massive white to pale green, pumiceous, faintly bedded tuff, containing a few sand beds and interbedded porphyritic basalt. Tuffaceous sands at the top grade into the Mulholland. Some joints are present in the middle tuffs. Opaline chert in 5-inch bands is associated with the extrusive basalts.

Local and very limited flows of coarse-grained basalt occur in the middle tuff unit. Large phenocrysts of complexly twinned and zoned euhedral plagioclase, some altered olivine, and augite make up the porphyritic basalt which has a subophitic groundmass. The phenocrysts are intermediate labradorite and the coarse groundmass feldspar is calcic andesine.

The distinctly bedded appearance of the Pinole tuff may be a result of subaqueous deposition. Contemporaneous sedimentation is indicated by included lithic fragments and interbeds of fine-grained sandstone. It is probable that much of the upper Pinole was formed in a lacustrine environment. Stirton[51] assigned a middle Pliocene age to the Tice Valley section on vertebrate evidence.

Quaternary System

Undifferentiated Pleistocene and Recent Units. The Quaternary deposits consist of terrace remains and valley fill, the latter being found extensively in the San Ramon Valley and in narrow strips on canyon bottoms. The deposits consist of interbedded fine silt, sand, and gravel comprising reworked Tertiary material. Such deposits rest unconformably on all older units.

Landslides have developed on steep slopes, where underlying rocks are composed of incompetent shales and sands, or in fault zones. Much of the northeastern slope of Rocky Ridge (Orinda-Mulholland formations), as well as the southeastern flank of Las Trampas Ridge are severely affected. Crow Canyon road in the southeast corner of

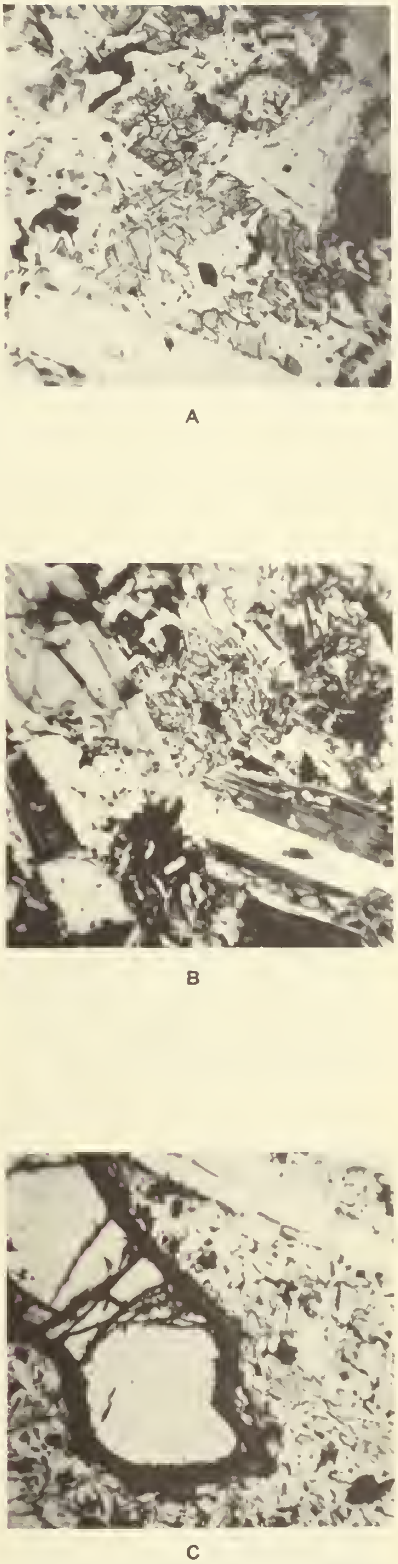

FIGURE 17. Photomicrographs of coarse porphyritic basalt interbedded as flows in the Pinole tuff, and of the Pinole tuff. Magnification 60x. (*A*) Plane polarized light. Ophitic basalt; inclusions in feldspar in linear arrangement. (*B*) Crossed nicols. Same as (*A*), showing zoning. Labradorite phenocrysts set in groundmass of andesine laths and augite. (*C*) Plane polarized light. Olivine phenocryst altered in part to deep red-brown iddingsite. From a coarse basalt flow.

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[49] Lawson, A. C., Op. cit., 1914.

[50] Vitt, A. W., The Pinole tuff east of San Francisco Bay: Univ. California, Unpublished Master's thesis, 1936.

[51] Op. cit.

the quadrangle became virtually impassable as a result of landsliding in the Bolinger fault zone during the winter rains of 1951.

Igneous Rocks

Analcite-Bearing Olivine Diabase. Dark gray diabase occurs on the southwest flank of Rocky Ridge in section 34 in an ellipsoidal knob about 50 feet in length,[52] projecting several feet above the surrounding countryside. This is the sole occurrence of analcite-bearing olivine diabase in the area. The spatial relationship of the volcanic rocks to Orinda-Mulholland sediments is not clear, for boulder float from the prismatic jointed diabase obscures all but one contact. On the northeast side of the exposure, coarse-grained blue-gray sandstone and pebble conglomerate show a narrow bleaching zone in contact with aphanitic to glassy vesicular diabase. A few boulders on the southwest periphery are faintly banded and exhibit the same surface texture. They appear to be in place. The high central mass is porphyritic and in places shows a crystalline groundmass in hand specimens. It seems probable therefore that at least on two sides aphanitic facies grade into coarser diabase toward the center.

As the long dimension of the body parallels the bedding of the adjoining sediments, which are steeply inclined at this locality, the diabase may constitute a limited surface flow. However, a diabasic texture coupled with the marginal aphanitic facies on at least two sides, indicate some type of hypabyssal intrusion with rapid marginal cooling. The vesicular, and in some places the glassy margin, are therefore probably a result of injection into porous wall rock. Microscopic examination of the olivine diabase and the basalt interbedded with the Pinole tuff showed them to be totally dissimilar rocks.

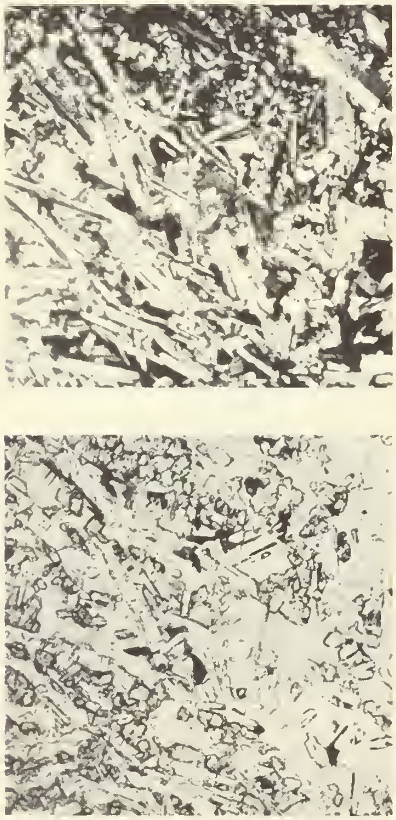

Figure 18. Photomicrographs of fresh analcite-bearing olivine diabase. Same orientation under plane and crossed nicols. Magnification 60x.

The analcite-bearing olivine diabase, being essentially similar to the altered diabase dikes in the Berkeley Hills,[53] is thought to be of the same mode of occurrence and contemporaneous in age. The intrusions may antedate the chief Cenozoic folding, but proof here is not conclusive.

Several sections from fresh diabase from the central part of the body have a microporphyritic diabase texture whereas sections from the contacts are typically cryptocrystalline to glassy with occasional elongated plagioclase laths oriented in a subparallel manner. In the former, microphenocrysts of labradorite (average An_{57}) and olivine are set in a groundmass consisting of plagioclase microlites (An_{34-55}), granular augite, and analcite, and minor amounts of natrolite and metallic minerals. The contact facies are highly altered plagioclase pseudomorphs after olivine, and calcite being the only recognizable constituents.

Minor minerals present include ilmenite needles, other metallic minerals as dust, brown glass(?), secondary carbonate (in contact areas only), and a few chalcedony or opal amygdaloids.

Chemical analyses	I	II	III	IV	V	VI	VII
SiO_2	46.92	47.83	45.59	50.55	48.22	48.8	48.8
Al_2O_3	17.86	15.31	12.98	20.48	14.82	15.8	16.0
FeO	5.94	9.22	4.70	4.02	9.25	6.3	6.3
Fe_2O_3	1.87	1.15	4.97	2.66	.56	5.4	4.3
TiO_2	1.08	2.86	1.32	--------	2.68	1.4	1.9
MnO	.15	.36	.14	--------	.23	.3	.2
CaO	9.44	12.38	11.09	7.30	8.81	8.9	8.2
MgO	8.06	6.60	8.36	4.24	5.58	6.0	5.4
K_2O	.21	.40	1.04	2.27	.44	1.6	2.8
Na_2O	3.32	2.53	4.53	8.37	4.95	3.2	3.9
H_2O	1.09	.28	.51	.44	.15	1.8	1.5
H_2O	4.02	1.28	3.40		2.54		
CO_2	nil	.05	--------	--------	1.40	--------	--------
P_2O_5	.09	.16	.91	--------	.23	.5	.7
BaO	--------	--------	.13	--------	nil	--------	--------
Totals	100.05	100.44	99.87	100.33	100.26		

I—Analcite-bearing olivine diabase (82-113).
II—Crinanite from Shiant Isles (Walker, 1930, p. 371).
III—Analcite basalt from Colorado (Clarke, 1900).
IV—Analcite, diabase, San Luis Obispo County, California (Fairbanks, 1895, p. 293).
V—Spillte from Nundle, New South Wales (Benson, 1915, p. 139).
VI—Average basalt (161 analyses) (Daly, 1914, p. 27).
VII—Trachybasalt (28 analyses) (Osann-Rosenbusch, 1923, p. 460).
The chemical analysis of sample 82-113 was made by W. H. Herdsman.

GEOLOGIC STRUCTURE

The area, lying within the Berkeley Hills synclinorium which is bounded on the east by the Sunol fault and on the west by the Hayward fault, is dominated by a subparallel alignment of longitudinal high-angle thrust faults and by several persistent open folds cut by transverse normal faults. The major structures trend N. 35° W., with few exceptions, and dips are high or even overturned in the vicinity of faults.

Late Pliocene, then Pleistocene diastrophism continuing to the Recent, culminated gentle compressive movements initiated during the Miocene epoch.

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[52] To emphasize this diabase the symbol used on the areal geology map is exaggerated 10X.

[53] Page, B. M., The geology of the Broadway tunnel, Berkeley Hills, California: Econ. Geology, vol. 45, pp. 142-166, 1950.

Folds

Kaiser Creek Syncline. Newton[54] referred to the Kaiser Creek syncline in the Hayward quadrangle as the San Pablo syncline. The name Kaiser Creek syncline is suggested here to prevent confusion over the well known place name.

The asymmetrical nature of this fold can be seen in several places, the best being on a prominent spur east of the Cull Canyon road. There freshwater limestone lentils on either side of the syncline trough converge on one another down either flank of the spur. To the northwest the fold changes from an axial plane overturned to the northeast to one overturned in the opposite direction. Flexures in axial planes of the various folds in Las Trampas Ridge area are common, and are believed to depend on the competency of the rock units involved, the proximity of fold to fault, or on subsequent slight folding of axial planes. The warping of the axial plane of Kaiser Creek syncline can be attributed to the nearby Cull Creek fault which cuts the northeast limb. Both flanks of the syncline are complicated by major faults and by plunging folds of small magnitude, so that the resulting structure is that of a faulted synclinorium. The minor folds of the northeast limb appear to coalesce in the northern quarter of the syncline's extent and are replaced by a simple homocline to the south, which in turn is terminated by Bolinger fault. On the northern flanks of Rocky Ridge the synclinal limb is nearly vertical to slightly overturned. Surface creep of the incompetent Neroly strata is responsible for part of the apparent overturning.

Las Trampas Anticline. The areal extent of Las Trampas anticline is considerably greater than recognized by Lawson.[55] Roads, numerous fire trails, and recently cleared land now offer exposures that were not available to earlier workers.

Using the distinctive middle Briones and Rodeo members as the main key markers, Las Trampas Ridge was recognized to be a complexly faulted partly overturned and partly asymmetrical anticline. Resistant rocks of the San Pablo group form highlands on the southwestern limb and poor exposures of the same group just west of San Ramon Valley are attributed to a recently uplifted, partly soil-covered terrace remnant which may mark the position of part of the ancestral San Ramon Valley. During the course of cutting this valley the northeast flank of Las Trampas anticline was bevelled. Closure on the Rodeo member can be traced with difficulty in sections 9, 14, 23, and 30. Overturning of the eastern flank is shown by stratigraphic sequence, inverted pelecypod valves or casts, graded bedding, and by channeling effects. By following stream bottoms in section 24 it is possible to trace the anticline from normal to reversed limbs. Apparent overturning in the vicinity of Las Trampas Peak is merely the result of downward creep of the Neroly member.

In mapping the major longitudinal fault traces flanking Las Trampas Ridge, the following observations were made: (1) Las Trampas fault to the north is a high-angle thrust cutting obliquely across the crest of the anticline; (2) west of Danville, Las Trampas anticline is overturned as much as 20° past vertical, perhaps because of a buttressing effect against the Sunol fault in San Ramon Valley; (3) south of Danville the overturn passes into a steep asymmetrical anticline, the axial plane still dipping to the southwest.

It is believed that a sequence of compressional forces first uplifted the fold, further compression developed longitudinal thrusts, and finally partial release of the compressional forces accompanied by uplift produced the transverse normal faults. Plunge of the segmented anticline is generally to the northwest.

Tice Valley Syncline. The Tice Valley syncline is bounded by two major high-angle thrusts that extend into the San Ramon Valley. Within the acute angle formed by the junction of the faults with the concealed Sunol fault the deposits are tightly folded and in many places overturned. Overturning is to the northeast as much as 15° past the vertical. Tice Valley syncline to the northwest, away from major faults, becomes shallower. Exposures of the San Pablo group show the asymmetrical nature of the fold and also the monoclinal northeast flank underlying Tice Valley.

Lawson[56] mapped a closed syncline using the Pinole tuff and overlying Pliocene deposits as markers in the northeast quarter of section 14. However, the highest sands and shales exposed along dirt roads traversing this area are upper Neroly, the tuff being absent. In the northwest quarter of section 14, middle Pliocene tuff is well exposed at a lower elevation than the previously mentioned upper Neroly. By projecting a line from the same horizon in the Neroly, a plunge of approximately 6° northwest is computed for the fold.

Faults

Miller Creek Fault. The Miller Creek fault heretofore has not been recognized. Recently constructed roads and newly developed quarry cuts have exposed geology that was formerly concealed. The fault zone is exposed along two roads that diverge northward from San Leandro Creek Canyon near its confluence with Miller Creek. Within the fault zone highly sheared and folded Monterey chert is seen above and adjacent to brecciated, veinleted, and slickensided Orinda conglomerate.

The degree of drag folding in the chert lessens to the southwest away from the fault. Continental deposits on the northeast side of the fault zone are dragged into a series of parallel-trending northwest-plunging folds that die out into Kaiser Creek syncline. Angular cobbles of Monterey chert within the Orinda here may represent fault-scarp erosion of an ancestral pre-late Pliocene Miller Creek fault, or, more likely, arched areas to the west were being stripped of their chert cover during early Pliocene time. Isolated remnants of this cover lie unconformably on the Cretaceous in the San Leandro Hills along Redwood road.

In addition to road-cut exposure of the fault zone, a fault line, sometimes a fault-line scarp, can be traced. There is, along the line of faulting, sudden thickening and thinning of Monterey sandstone some of which, being resistant units in comparison to the Orinda, stand as a prominent resequent fault-line scarp. To the southeast the fault trace gives way to a bundle of tight folds within Briones shell beds. This may indicate rotational movement along the fault, the southwest block having been sheared and thrust up on a pivot of unbroken folds to the southeast in the manner of a break thrust. The fault plane, which is partly exposed by Miller Creek, dips approximately 75° SW.

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[54] Newton, R. J., Op. cit., 1948.
[55] Lawson, A. C., Op. cit., 1914.
[56] Lawson, A. C., Op. cit., 1914.

It is difficult to determine the amount of displacement on the Miller Creek fault. The Orinda conglomerate may be equivalent in time to the upper San Pablo group rocks cropping out along Rocky Ridge. To the southeast the Briones member is in contact with Orinda beds, and Cierbo-Neroly rocks are absent. The thickness of Monterey and Briones rocks below the Orinda beds on the northeast fault block is unknown and the thickness of Orinda units in this vicinity is unknown. Therefore the 2,000 feet displacement represented on cross section E-E′ is hypothetical.

Cull Creek Fault. The Cull Creek fault appears to be primarily a bedding thrust in the south and a break thrust as it passes out of the area to the northwest. As both blocks are in the Orinda-Mulholland group of rocks the fault trace is difficult to fix precisely. An appropriate position can be determined however by field criteria such as (1) possible repetition of freshwater limestone lentils in sections 11 and 12; (2) presence of drag folds on the downthrown block that are truncated obliquely along a line the upthrown side of which is generally little disturbed; (3) alignment of numerous springs, slides, and topographic saddles regardless of topography and lithology; (4) overturning of strata not confined to places where slumping would be favored by slope; (5) three wide zones of intense brecciation in varying lithology (sections 11, 12, 3, and 34), which dispel the possibility of simple adjustment of an incompetent unit between two that are competent.

The Cull Creek fault projected northwest along its strike may join the Moraga fault in the Briones Valley quadrangle, where 6,000 feet of displacement has been assumed by Savage and associates.[57] Newton [58] does not map the fault in Hayward quadrangle. By using the possibly repeated limestone lentils, an approximate displacement of 1200 feet can be computed for the fault in section 11. To the northwest the throw is probably greater, although no evidence other than the existence of the Moraga fault supports this; to the southeast the fault in all probability dies out or is cut by transverse faulting.

Bolinger Fault. The Bolinger fault may be traced through the entire area by means of a well-developed fault-line scarp trending along the northeastern flank of Rocky Ridge. This is produced by competent Briones beds thrust against incompetent Orinda-Mulholland units. Whether it is a break thrust or a bedding thrust is not clear.

Many have recognized the existence of Bolinger fault. Newton [59] who recently studied it, noted that the fault plane may be vertical in some places. The author believes that the thrust may have an average dip of 55° SW in the south, but that it reaches a near-vertical position in proximity to Las Trampas peak. Field evidence, which supports this contention, may be summarized as follows: (1) a sinuous fault trace along the southern half of Rocky Ridge replaced to the north by one that is straight is interpreted as a moderately inclined thrust steepening in this direction to nearly vertical; (2) middle Briones reef beds dip at low angles along the fault trace, especially in sections 1, 6, and 35, whereas the adjacent Orinda-Mulholland is steeply overturned or moderately inclined; (3) the possibility of drag folding in the upthrown block seems ruled out by observed fault contacts; at the northern end of section 35, Briones beds overlie Orinda-Mulholland units; an abandoned adit in section 6 follows along a shear zone inclined moderately to the southwest; at no time does this working cross a fault zone where two walls may be recognized; (4) many outlier-like masses of middle Briones rocks are in the northeast overriding Orinda-Mulholland beds; these are interpreted as massive slides disengaged from the thrust because of undermining of easily eroded Orinda-Mulholland sediments; (5) the inferred sliver fault block, as presented in cross-section F-F′ appears to ride out on continental deposits and a slickensided and brecciated zone, with many seeps, marks its base.

Complex faulting possibly exists at the northwestern end of Rocky Ridge. The Bolinger fault here swings abruptly to the west and then back to a northwest trend. Transverse faults through Las Trampas peak may conceivably continue to Rocky Ridge, causing northeasterly offset to the earlier Bolinger thrust.

Displacement along the thrust, as determined on cross-sections E-E′ and F-F′ may approximate 5000 feet.

Grizzly Fault. As mapped in section 16, a syncline of continental strata abuts against and is cut by the Grizzly fault. To the north this normal fault is less clearly exposed, but apparently cuts obliquely across increasingly older marine units. South of Las Trampas peak the fault line is obscure. Two possibilities exist: (1) that the trace passes into incompetent Orinda-Mulholland rocks down Bolinger Canyon and is lost, or (2) that it swings east to join a transverse fault cutting Las Trampas anticline. The latter would entail downward movement on a curved trace and, where the fault becomes transverse, would have to be offset to the northeast. It seems likely that this complicated sequence is untenable, so the first possibility is favored.

The Grizzly fault is interpreted as a gravity fault that resulted from compressional release and uplift. It postdates the main period of thrusting, and perhaps is contemporaneous with the transverse faulting.

Las Trampas Fault. Lawson [60] projected Las Trampas fault along the precipitous front of Las Trampas Ridge, eventually to be terminated by the Sunol fault in the vicinity of Danville. Evidence for the extent of Las Trampas anticline and its associated longitudinal fault has been discussed previously, but further elaboration of the position of the fault line is necessary.

Over its entire course Las Trampas fault zone is marked by topographic lows. Stream erosion and heavy vegetation along its course obscure most traces of the fault zone, but in sections 13 and 14 veins and slickensides on the more competent units are exposed. The fault is believed to have broken across the crest of Las Trampas anticline, resulting in a southwest-dipping fault plane that is essentially parallel to the axial plane of the anticline.

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[57] Savage, D. E., Ogle, B. A., and Creely, R. S., Op. cit., 1951.
[58] Newton, R. J., Op. cit., 1948.
[59] Op. cit., 1948.
[60] Lawson, A. C., Op. cit., 1914.

Clark[61] dates this fault as pre-upper Miocene, attributing unequal thicknesses of San Pablo on either side of the fault to movement during deposition. This irregular deposition on either side of the fault line is not apparent in Las Trampas Ridge area.

Although a maximum net slip of 4,000 feet is estimated, initial displacement along the thrust has been complicated by a reversal in movement. It is for this reason that two distinct movements have been interpreted along cross-section D-D′ where an apparent anomaly exists. Briones sandstone on either side of the fault is in a reversed position if upthrusting on the southwest side is accepted. Gravity faulting post-dating the thrust could explain the present reversed position.

Franklin and Sunol Faults. The northwest projection of the Sunol fault where it passes out of the San Ramon Valley is regarded by the author as the Franklin fault. Sunol fault extends from Tres Pinos (near Hollister) on the south to Alamo in San Ramon Valley. Its possible extension north into Napa County may be the Franklin fault. These faults are pre-Miocene according to Clark[62] and Taliaferro[63] and bound the Berkeley Hills synclinorium on the east. Sunol fault is believed to lie below the alluvium of San Ramon Valley. The previously described alluviated and uplifted terrace remnants on the southwest side of the valley may reflect Pleistocene faulting along the Sunol fault at which time the downthrown and upthrown sides were reversed.

Vickery[64] estimates as much as 12 miles horizontal displacement in the Livermore area. Erickson[65] visualized vertical displacement of 5,500 feet, the westerly block being upthrown.

Franklin fault represents a longitudinal break across the crest of a northeasterly overturned anticline. The northeast block has moved up in relation to the southwest with considerable but undetermined displacement being involved. This movement is the reverse of other thrusting within the area. Horizontal movement may have accompanied thrusting but there is no definite evidence for this. An interesting feature of Franklin fault is the variation in attitude of its fault plane. In the vicinity of Castle Hill, where Tertiary formations of the northeast block are overturned, the fault is nearly vertical. Two and one-half miles to the northwest the fault plane is dipping 35° to 40° northeast. This steepening and slight folding of the fault plane can be attributed to the structural complexity of several en echelon faults and folds joining the Sunol fault south of Castle Hill.

Transverse Faults. Las Trampas anticline and other structural features are cut by a series of transverse gravity faults, having right lateral movement, that postdate the main thrust faults in the area. Lawson[66] first noted the transverse fault near Las Trampas peak. This type of fault has caused offsets of formational contacts and structural features of as much as 1,500 feet. It is likely that the gravity faults swing obliquely into the main thrusts, or become bedding faults and are lost. Differential displacement of Pleistocene terrace remnants overlooking San Ramon Valley gives evidence of continued movement along these faults as well as along Sunol fault.

On the southwest flank of Las Trampas Ridge, in section 22 (fossil locality 20), several small dip-slip diagonal faults were studied in three-dimensional detail. These are thought to be directly related to the transverse faulting. A complete fault plane trending northeast showed the following: (1) a fault-gouge zone up to 3 inches wide separating walls with 7 to 10 feet diagonal displacement; (2) a fault plane dipping 50° to 70° SE., (3) slickensides plunging to the northeast showing chatter marks or steps trending at right angles to the striations. Movement, as computed from these data, has lowered the hanging wall diagonally to the northeast.

Periods of deformation.

Age	Type of deformation	Area affected
Post-Cretaceous, pre-Miocene	Folding and block faulting	SW. corner of quadrangle
Upper Pliocene through lower Pleistocene	Extreme compression and reversal of movement on ancestral normal faults.	Entire area strongly deformed, folds overturned, thrusting of adjacent blocks over former trough.
Pleistocene	Uplift followed by block faulting.	Transverse right lateral faulting from compressional release along Las Trampas anticline and elsewhere.
Recent	Continued uplift	Horizontal movement on Sunol fault to the south.

GEOLOGIC HISTORY

As Upper Cretaceous marine deposits in Las Trampas Ridge area are limited to considerably less than half a square mile, little can be said about Cretaceous geologic history. Work in other areas indicates that the deposits were derived from the west from a land mass composed of acid plutonic rocks and a roof cover of metamorphic rock, probably Sur series. Fringes of earlier Cretaceous sediments on the margin of the elevated western land mass presumably were also eroded, as earlier (?) Cretaceous debris is mingled with the granitic and metamorphic rocks found in the Cretaceous rocks of Las Trampas Ridge area. The abundance of carbonized wood fragments in these rocks suggests that the western land mass was well forested. The end of the Cretaceous was probably marked by withdrawal of the sea.

From the close of the Cretaceous to upper Eocene land areas may have persisted in Las Trampas Ridge area. Eocene and Oligocene marine units are absent in the southwest where middle Miocene rocks directly overlie the Cretaceous. The relationship of upper Eocene to Cretaceous elsewhere in the area is not known. However, there is the possibility that marine Eocene and Oligocene blanketed the entire region and that pre-Monterey erosion stripped off all that was present in the southwest. The Eocene epoch closed with warping and some erosion, which persisted to the upper Oligocene. The Sunol fault is thought by some to have originated during the Eocene as a normal fault.

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[61] Clark, Bruce L., Age of primary faulting in the Coast Ranges of California: Jour. Geology, vol. 40, pp. 385-401, 1932.

[62] Clark, B. L., Age of primary faulting in the Coast Ranges of California: Jour. Geology, vol. 40, pp. 385-401, 1932.

[63] Taliaferro, N. L., Op. cit., 1943.

[64] Vickery, F. P., The structural dynamics of the Livermore region, California: Jour. Geology, vol. 33, pp. 608, 628, 1925.

[65] Erickson, M. R., Geology of the western portion of the Pleasanton quadrangle, California: Univ. California, unpublished Master's thesis, 1945.

[66] Lawson, A. C., Op. cit., 1914.

Marine upper Oligocene sandstone was laid down on tilted bevelled Eocene beds. Contemporaneous dacitic or andesitic volcanism is indicated by the tuffaceous nature of the sediments. This was the first volcanism recorded in the area. Again, a period of emergence and erosion is indicated during the lower Miocene, as the Monterey beds unconformably overlie the partially eroded San Ramon formation.

Warping, tilting, and erosion have been demonstrated previously by small unconformities existing between Eocene and Oligocene, and between Oligocene and middle Miocene; but the aggregate intensity of these Cretaceous to pre-Monterey movements is best illustrated by the profound angular unconformity existing between the Cretaceous beds and Monterey units in the southwest corner of the area. By middle Miocene time, widespread marine submergence took place, and the Monterey beds were unconformably deposited over all the previous units.

By upper Miocene time the siliceous Monterey units were covered by coarse clastics of the San Pablo group. It is believed that a series of irregular shallow-water embayments and straits received tuffaceous graywacke sandstone, which reflected a beginning of more intense uplift to the west. A Franciscan source contributed for the first time quantities of chert and eroded volcanics, which became more abundant by lower Pliocene time. Slight movements along buried faults may have taken place at this time, culminating in severe orogeny in the latter half of the Pliocene epoch. Debris carried to the basins was derived in part from local sources of terrigenous tuffs. Other sources of volcanic debris may have been as far east as the Sierra Nevada.

By late Miocene time, uplift was so pronounced as to cause a slow regression of the San Pablo seas to the east accompanied by encroachment of continental flood-plain deposits from the west. The Orinda on the southwest may then correspond to upper San Pablo (perhaps as low as the basal Cierbo) to the northeast. Overlap of marine units by continental beds continued into the lower Pliocene, at which time deposition of flood-plain deposits became dominant. These deposits are characterized by an abundance of Franciscan debris. Following a brief interval of explosive subaqueous volcanism in the middle Pliocene, lacustrine conditions followed close upon flood-plain deposition.

The periodic uplift from middle Miocene through the middle Pliocene was culminated by intense diastrophism, most probably guided by old lines of weakness. Compressive forces produced tight folds, in some cases overturned, and reverse faults. This post-Mulholland orogeny may have continued into the Pleistocene, accompanied by vigorous degradation and alluviation.

Reverse faulting may have continued into lower Pleistocene, but it was superceded by renewed uplift and then by subsequent transverse block faulting. The latter manifestation of compressional relaxation is noted in displacement of early Pleistocene straths which may represent an ancestral San Ramon Valley. Faulting, erosion, and alluviation continue to the present. Uplift in the Recent has initiated the present cycle of erosion.

ECONOMIC GEOLOGY

Limestone. Small lentils of fine-grained, blue-gray to white, impure limestone are common in the Orinda-Mulholland and Neroly units, especially in the southern half of the quadrangle. Tests have been made on a white limestone outcropping in the southwest quarter of section 6, but it was found unsuitable for lithographic purposes. Local residents have made use of small amounts of the blue-gray limestone as road metal.

On the Bolinger fault, in section 6, a small adit was driven along the fault zone. Pods of travertine encountered were apparently too small for economic exploitation and the adit was abandoned.

Crushed Rock and Gravel. Many quarries are situated in Bolinger and Cull Canyons, where Orinda-Mulholland gravels are worked for local fill and road metal. Elsewhere, sand and alluvial soil are bulldozed for commercial use in nearby real estate developments. One such enterprise is operated in the southwest quarter of section 10.

The East Bay Municipal Utilities District, in building the Upper San Leandro Reservoir dam, used chert and conglomerate fill derived from the Claremont and Cretaceous units nearby. Blasting was necessary to break up resistant aggregates of massive conglomerate, over 80 percent of which is composed of rounded crystalline rock.

A suggested, but as yet untapped, small source of trap rock is situated in section 34 on East Bay Municipal Utilities District property. Fresh diabase here crops out as a jumble of prismatically jointed boulders up to 4 feet in size. A dirt road leads up to the outcrop.

Pozzolan. Within Las Trampas Ridge area are two sources of pozzolan which might be exploited commercially. The Claremont member is predominantly an opaline chert, and the biotite vitric tuff within the San Pablo group approximates a rhyolite tuff. Both rock types are situated near main arterial routes, and within a short distance of San Francisco Bay area cement plants.

Water. Much of the area constitutes a watershed for the Upper San Leandro Reservoir. In general, East Bay Municipal Utilities District controls the region that is drained by southwestward-flowing intermittent streams originating near the crest of Rocky Ridge.

Many springs flow from fault zones, or from such units as the basal Briones where it is in contact with the Rodeo shale. Seasonal fluctuation of the water table caused by depletion during the dry season causes most of the springs to go dry periodically. Small supplies of water derived from such springs and shallow wells, however, are sufficient for domestic and stock purposes.

Most ranchers in the area maintain small reservoirs or wooden tanks in canyon bottoms which are replenished seasonally by piped gravity flow.

Oil and Gas. Drilling for oil and gas has not been attempted within the limits of Las Trampas Ridge quadrangle, although shallow wells with non-commercial shows of gas and oil have been drilled in adjoining quadrangles. Some production from the Monterey and Cretaceous is possible, in the writer's opinion. During the course of field work, two small oil seeps were seen, both along canyons that cut major thrust zones. Suitable structure and the possibility of gas-bearing Cretaceous rocks at depth, 1½ miles south of Danville, would bear further investigation.

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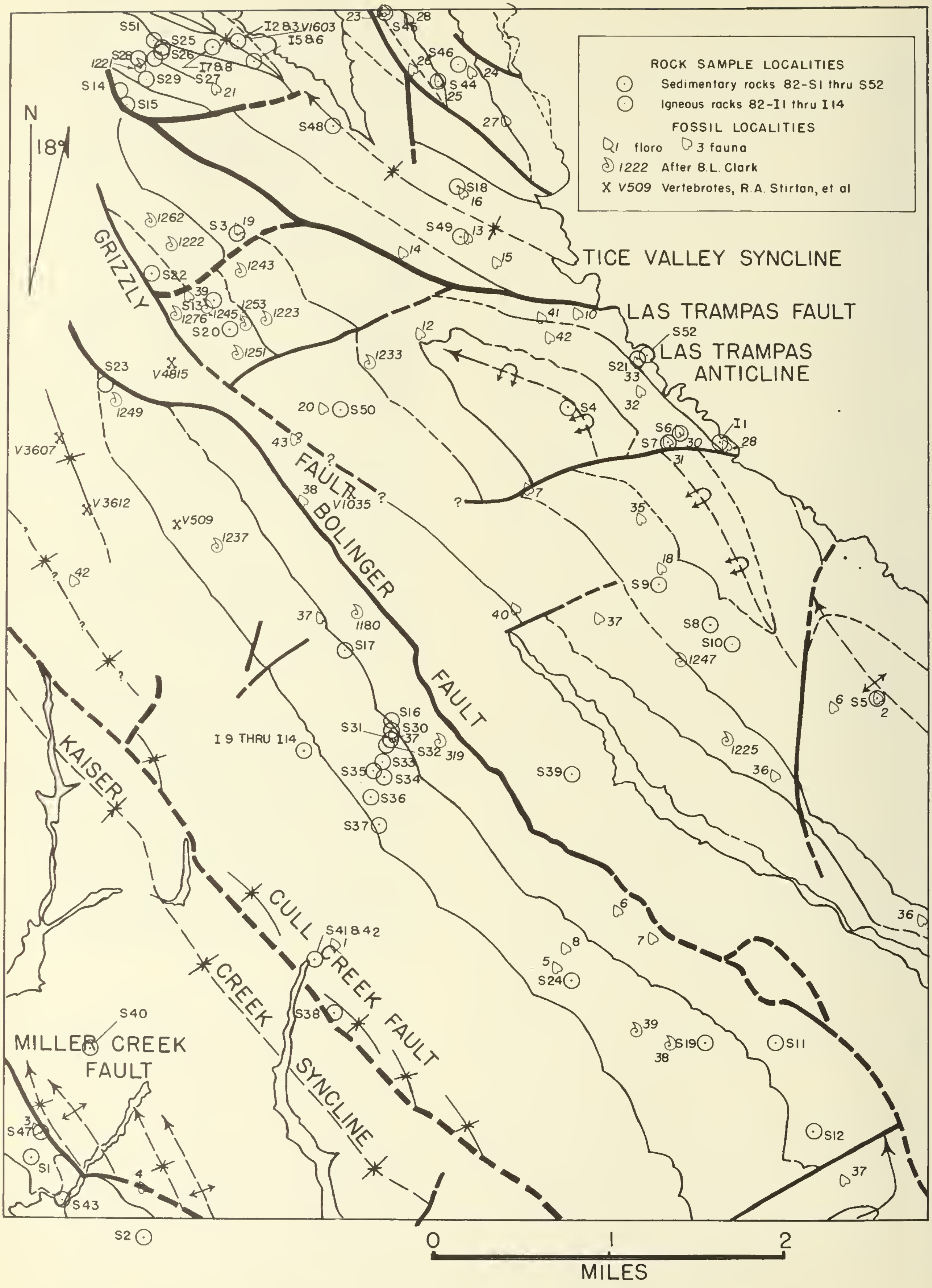

Figure 19. Map showing rock sample and fossil localities

APPENDIX

*Fossil localities, Las Trampas Ridge quadrangle.**

Map no.	U.C. loc. no.	Location			Fossil
		Sec.	T (S)	R (W)	
1		3	2	2	Salix wildcatensis (leaf)
		28	1	2	
2		31	1	1	Nassarius whitneyi
3	A7136	9	2	2	Dosinia mathewsoni Pecten andersoni Clementia sp. Amiantis sp. Chione sp. Tivela or Pachydesma sp.
4	A7137	9	2	2	Chione temblorensis
5	A7138	1	2	2	Solenosteira sp.
6	A7139	1	2	2	Astrodapsis brewerianus
		31	1	1	
7	A7140	1	2	2	Pecten andersoni
8	A7141	1	2	2	Pecten cf. andersoni
9	A7142	13	2	1	Amiantis sp. Anadara devincta Pecten andersoni Nassarius whitneyi
10		13	1	2	Neptunea cierboensis
12		14	1	2	Nassarius whitneyi Anadara devincta
13		14	1	2	Pecten crassicardo Calyptraea martini
14		14	1	2	Dosinia cf. merriami Pecten andersoni
15		14	1	2	Astrodapsis whitneyi var. Echinarachnius gabbi var. Pecten crassicardo
16		14	1	2	Ostrea bourgeoisii
17	A7143	23	1	2	Pecten raymondi brionianus
18		25	1	2	Pecten andersoni
19		15	1	2	Anadara devincta Tegelus sp.
20		22	1	2	Mulinea pabloensis Astrodapsis tumidus Astrodapsis whitneyi
21		10	1	2	Pecten crassicardo
22		3	1	2	Spisula falcata
23	A7144	11	1	2	Thais packi Dosinia mathewsoni Polinices sp.
24		11	1	2	Polinices sp. Spisula sp. Anadara devincta montereyana Yoldia cooperi
25	A7145	11	1	2	Echinophoria apta
26	A7146	11	1	2	Nitidavenus sp. Cancellaria sp.
27	A7147	11	1	2	Pecten andersoni gonicostus
28	A7148	11	1	2	Anadara montereyana Ostrea titan
29		19	1	1	Nassarius whitneyi
30		24	1	2	Pecten raymondi Nassarius whitneyi Anadara devincta Yoldia cooperi
31	A7149	24	1	2	Pecten andersoni gonicostus
32		24	1	2	Nassarius whitneyi
33		24	1	2	San Pablo fauna Shark's tooth
35	A7150	24	1	2	Pecten raymondi brionianus Brittle starfish
36	A7151	5	2	1	Pecten crassicardo
		31	1	1	
37		27	1	2	Ostrea bourgeoisii
		35	1	2	
		20	2	1	
38	A7152	22	1	2	Pecten raymondi brionianus
39	A7153	15	1	2	Astrodapsis tumidus Astrodapsis whitneyi Prorothaca staleyi Mulinea pabloensis
40		26	1	2	Astrodapsis whitneyi
41		13	1	2	Echinarachnius gabbi var.
42		13	1	2	Astrodapsis brewerianus
43		22	1	2	Mastodon
		28	1	2	

---

* These localities are shown on the map, figure 19. Specimens now retained by the University of California Museum of Paleontology are listed in the column "U. C. loc. no." and are numbered A7136 through A7153.

*Invertebrate fossil localities Las Trampas Ridge quadrangle, after Bruce L. Clark.**

Map no. and U.C. loc. no.	Location			Formation
	Sec.	T (S)	R (W)	
38	1	2	2	San Pablo
39	1	2	2	San Pablo
319	35	1	2	Briones
1180	26	1	2	Briones
1221	9	1	2	San Pablo
1222	16	1	2	Briones
1223	15	1	2	Briones
1225	31	1	1	San Pablo
1233	23	1	2	Briones
1237	27	1	2	San Pablo
1243	15	1	2	Briones
1245	15	1	2	San Pablo
1247	25	1	2	San Pablo
1249	21	1	2	San Pablo
1251	15	1	2	San Pablo
1253	15	1	2	San Pablo
1262	16	1	2	Briones
1276	16	1	2	San Pablo

---

* Catalogued at the University of California Museum of Paleontology, Invertebrate Collections, and shown on map (fig. 19).

*Vertebrate fossil localities, Las Trampas Ridge quadrangle, after R. A. Stirton.**

Map no. and U.C. loc. no.	Location			Age	Fossil
	Sec.	T (S)	R (W)		
V1603	10	1	2	Middle Pliocene..	Pliohippus (?)
V4815	21	1	2		
V1035	22	1	2	Lower Pliocene (Siestan)	Hipparion cf. mohavense
V 509	22	1	2	Lower Pliocene (Orindan)	Nannippus tehonensis
V3607	21	1	2	Lower Pliocene (Orindan)	Trilophodon simpsoni n. sp. Stirton
V3612	21	1	2	Lower Pliocene (Orindan)	Hipparion (?)

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* These localities are shown on the map, figure 19, and are catalogued at the University of California Museum of Paleontology Vertebrate Collections.

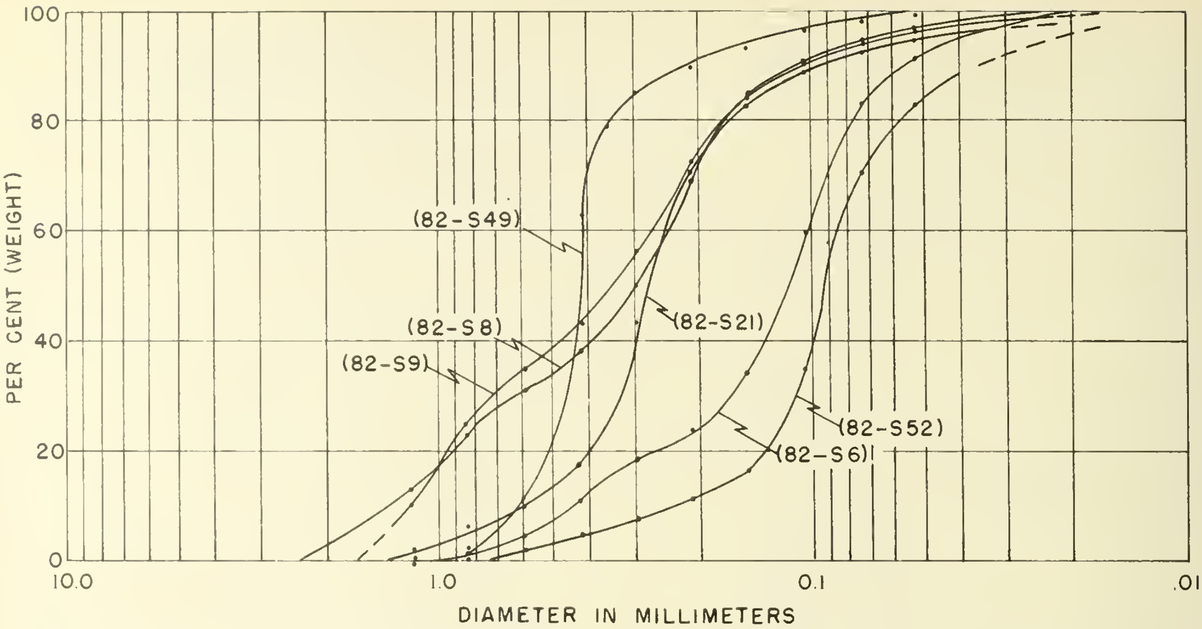

FIGURE 20. Cumulative curves showing sorting in San Pablo group sediments. Six sands of the San Pablo group are plotted as cumulative curves, five of which show poor sorting. The sixth curve, 82-S-49, represents a well-sorted beach sand in close proximity to pelecypod reef beds. This type has resulted from the panning away of all material except that of one general grade size by shallow-water currents. The other five sands cover a greater size range in the middle 50 percent and are characterized by a moderate percentage of clay and silt. The San Pablo units are mostly poorly sorted, silty, medium- to coarse-grained graywacke, but partly fine-grained silty graywacke.

Heavy and light mineral analyses.

Mineral	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Hypersthene	r	va	va	r	r	r			c	va	va	va	r	r	c		
Angite		va	a	c	c		c	r	r	c	a	c	c	va	va		
Basaltic hornblende		c	c	vc	r	a	c	c	a	a	vc	c	c	r	c		
Green hornblende	c	c	c	va	a	va	va	va	va	c	c	va	va	a	c		
Brown hornblende					r	a	a	a						c			
Actinolite					c		r	r		r						c	a
Epidote	c		c	c	a	c	c	r	r	a	c		vc	c		c	a
Glaucophane					r	r			r		r		r			a	a
Pumpellyite					r											r	r
Lawsonite																c	c
Staurolite									r								
Biotite	a					c	r		c		r						
Chlorite	r				c							r		r		a	c
Tourmaline	a															r	r
Garnet	c	r		r	c				r				r	r		r	c
Zircon	a	r		r	va	r	r		r				r			vc	a
Sphene	c	r			c	r			r		r		r	r		r	c
Rutile	r				c												r
Glauconite				r	r	r	r	r	r	r	r	r	r	r	r		
Opaques	a	r			va		a	a		a	a	c			a	va	a
Quartz	a	c	vc	a		vc	c	va	va		c	c	c	c			
K-feldspar	c	r	r	c		c	c	c	r	c	r	r	r	a			
Plagioclase	c	vc	vc	vc		r	c	vc	c	a	vc	vc	c	a			
Glass		a	a	c		c		r	a	r	c	a	r				
Chlorite	c		r				r	c		r	r	c		r			
Clays							a			va	a	va	va	va			

va—very abundant a—abundant vc—very common c—common r—rare

A—82-S43, Cretaceous; B—82-S44, San Ramon; C—82-S45, San Ramon; D—82-S46, Monterey; E—82-S47, Monterey; F—82-S5, Briones; G—82-S9, Briones; H—82-S8, Briones; I—82-S6, Briones; J—82-S21, San Pablo; K—82-S26, San Pablo; L—82-S48, San Pablo; M—82-S49, San Pablo; N—82-S50, San Pablo; O—82-S51, San Pablo; P—82-S41, Mulholland; Q—82-S53, Mulholland.

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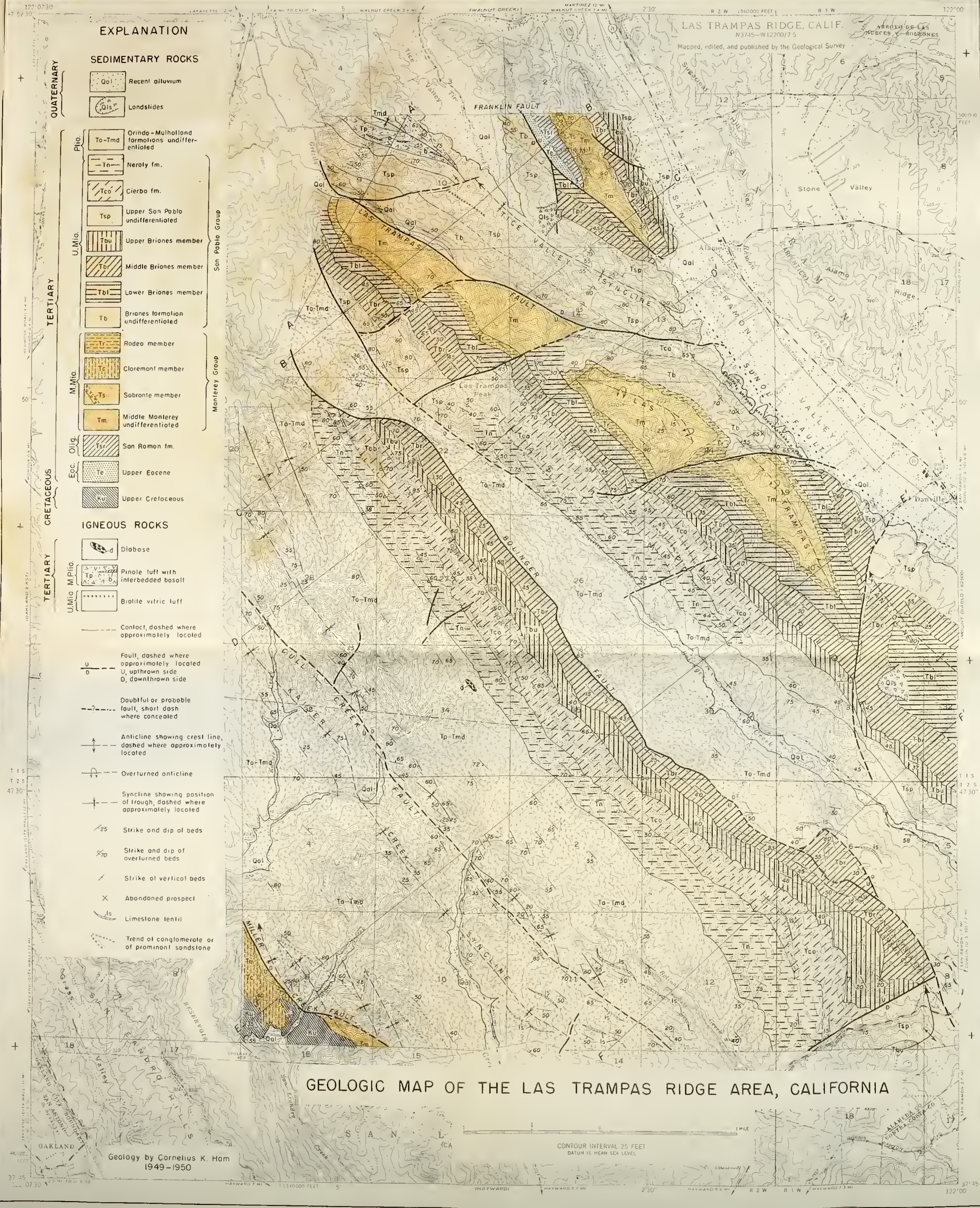
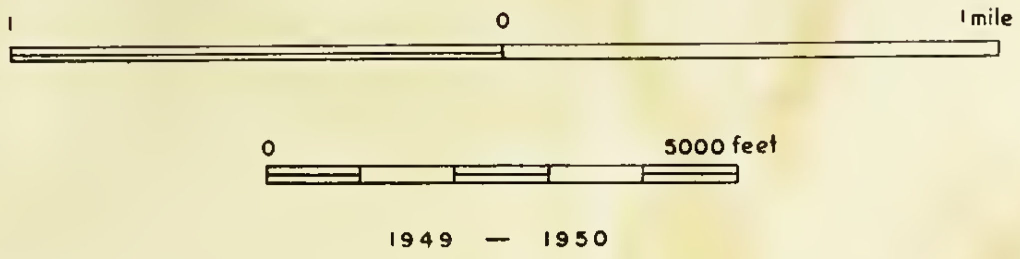
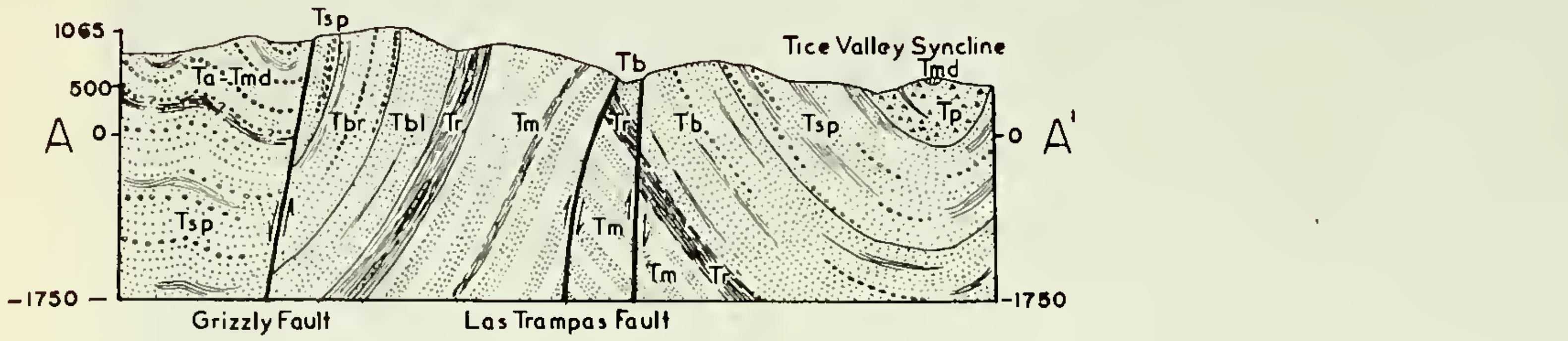
SPECIAL REPORT 22
PLATE 1

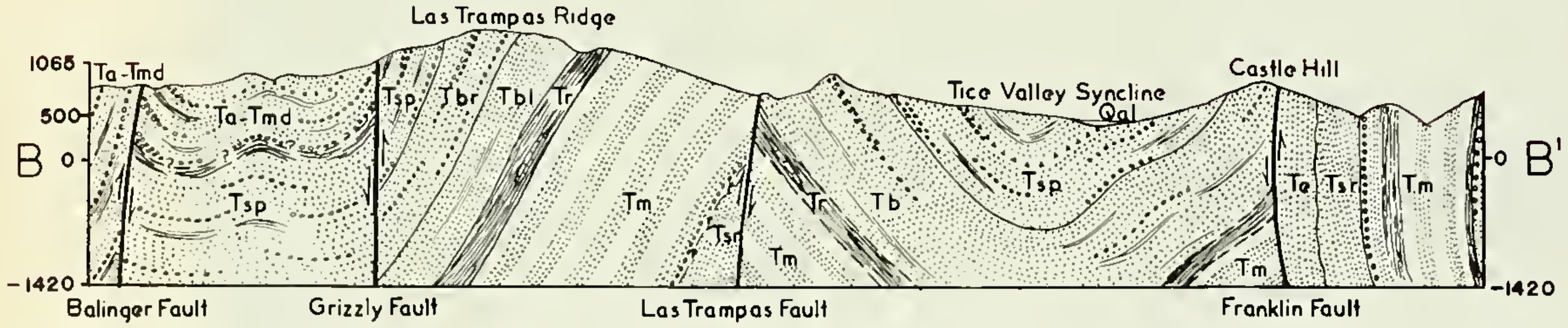


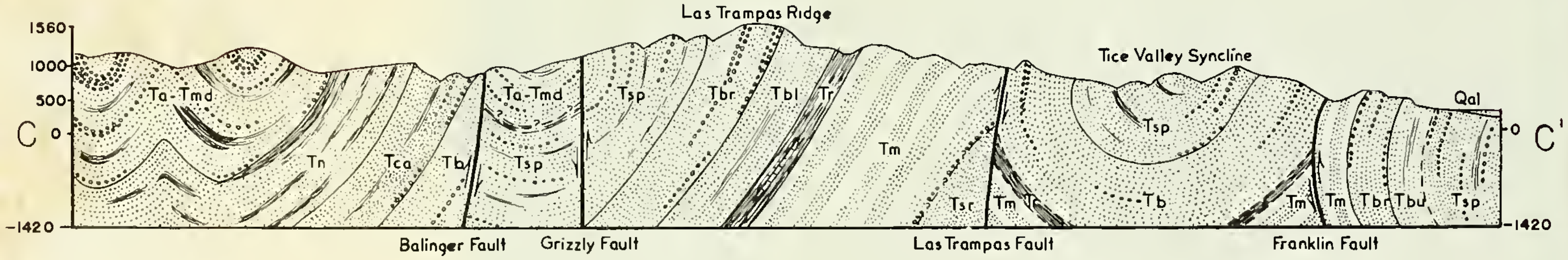
GEOLOGIC MAP OF THE LAS TRAMPAS RIDGE AREA, CALIFORNIA

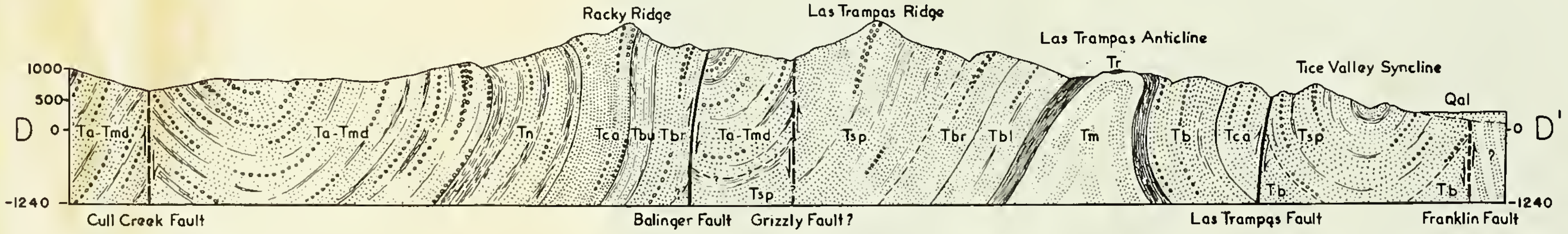
GEOLOGIC SECTIONS THROUGH THE LAS TRAMPAS RIDGE AREA, CALIFORNIA

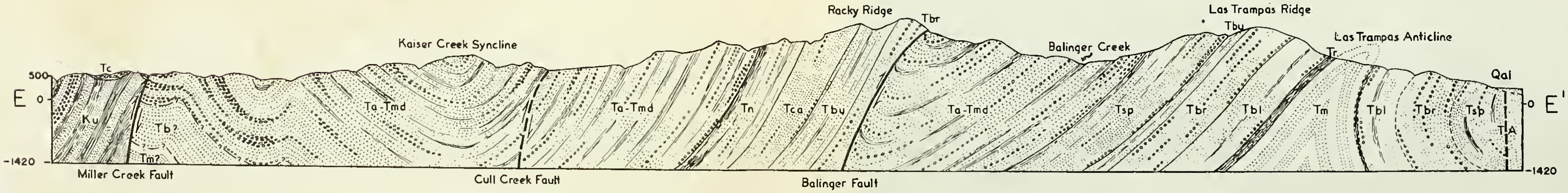


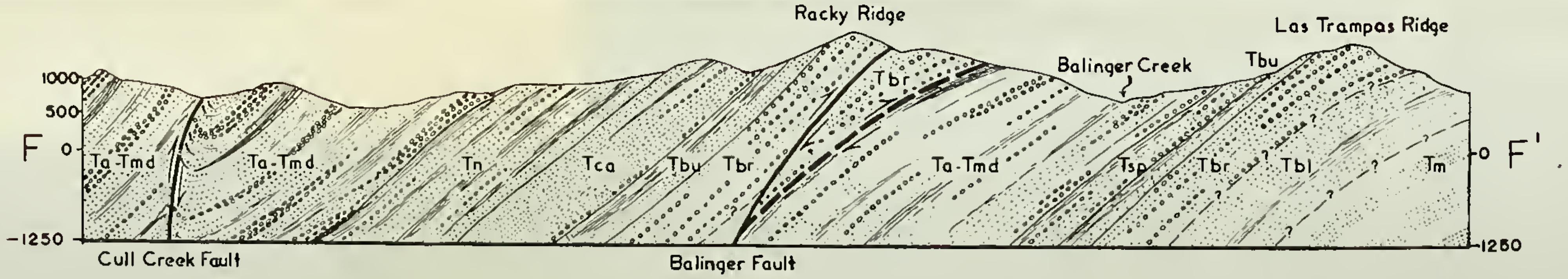












C. K. Ham